COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

June, 1944

Assembling C-E Boiler for Power Train

Inertia Effect of Variable-Speed Control of Induced-Draft Fan Wheels ▶

High-Pressure and High-Temperature Steam for Marine Use ▶

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VOLUME FIFTEEN NUMBER TWELVE

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FOR JUNE 1944

FEATURE ARTICLES

EDITORIALS

DEPARTMENTS

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EDITORIAL

Semi-Outdoor Plants

Indications point to continuance of high construction costs during the post-war period; perhaps not at the present level but assuredly above that of pre-war days, as there is little likelihood of wage scales reverting to former levels. This leads to some speculation as to how it may influence power plant design of the future, particularly building structures. Will it presage more semi-outdoor plants?

Plants of this type have long ceased to be a novelty. Many have been in service for the last ten or twelve years in varied climates and in both the central station and industrial power fields. The number is much larger than one would assume without an actual count and they appear to have been satisfactory in all respects. In general, such construction has been confined to medium-size installations. In most cases the turbine-generators have been housed and the boiler plant exposed, and in a few the reverse procedure has been adopted, with protection to the operating galleries.

Compared with the conventional fully housed plant, very substantial savings in building materials and labor are reported, and there is likely to be a reduction in maintenance. Operating economy is not affected.

It is not probable that such simplified construction will find application to large installations in metropolitan areas where the differential between the two types forms a proportionately smaller part of the total installation cost and where traditional conservatism is likely to favor the conventional design. However, within the already proved range, post-war economic conditions would appear to favor wider adoption of such plants.

Extra Home-Front Tasks

Everybody has heard of the "Dollar a Year Men" at Washington—leaders in industry who are contributing their time and experience to furthering various phases of the war effort. But their number is infinitesimal compared with the many thousands of business men and engineers throughout the country who are freely giving their time to innumerable war activities. Upon them depends most of the organization work for bond drives, Red Cross and similar campaigns, but in addition to these widespread projects in which the general public participates, there are innumerable other campaigns calling for their specialized knowledge, such as re-employment studies, post-war planning, national publicity to conserve paper and other strategic materials, production clinics and the recently inaugurated Fuel Conservation Program. The last mentioned alone will require the active participation of several thousand engineers and valuable assistance has already been rendered by several trade associations in the preparation of forms and helpful information.

Full credit is due these individuals who have taken on such home-front duties, often in addition to their regular work because of manpower shortage or when it cannot be delegated to others. But aside from this, the companies that employ them are to be highly commended not only for their financial support but for their unstinted cooperation in making available the services of executives and other key men. This has been especially true of the larger corporations.

If it were possible to evaluate in dollars the time thus gratuitously contributed, the total would represent a staggering sum. Unfortunately, little of this is known to the general public. It it were, the business world would be better fortified against the attacks of malcontents and politicians.

Power Trains

Very little has appeared in print concerning the destruction of power plants in battle areas as well as by bombing far within enemy territory. That such destruction must be considerable is conceivable from the fact that power plants are one of the primary objects of attack as a means of crippling enemy production and hampering military efforts. Moreover, they have usually been objects of systematic demolition by retreating forces in order to impede the re-establishment of civilian life in captured cities and towns. In some cases, the destruction is reported to have been so extensive as to preclude restoration of service; in others it has been such as to require weeks for repairs. Months would be required to erect new power equipment. Meanwhile, lack of electricity supply to serve the most essential civilian and military needs constitutes a serious handicap.

It was in anticipation of such situations that the Allied Governments some time ago wisely undertook the planning of a large number of mobile steam power plants, mounted on railway cars, that could be readily shifted to localities where most needed. Of these a considerable number are now nearing completion in the United States, and have received more or less publicity in the daily press under the designation "Power Trains." These are built in sizes of 5000, 3000 and 1000 kilowatts in order to provide flexibility in meeting individual local requirements.

Because of the wide range in localities where they are likely to be employed, many unique problems in design were involved. These include the meeting of limitations imposed by railway clearances in various countries, axle loading, the possibility of having to burn very low grade coals, ability to operate in either torrid or frigid zones and scarcity of water supply.

These Power Trains have already been discussed informally at several engineering society meetings, one of which is briefly reported in this tissue. It is expected that COMBUSTION will be privileged to give further details in a forthcoming issue.

Inertia Effect of Variable-Speed Control of Induced-Draft Fan Wheels

By Murray S. Kice, Ch. Engr.

American Blower Corporation, Detroit

This study is to illustrate that the use of straight variable-speed mechanical-draft fan drive is no deterrent to practical rapid boiler load swings. Variable-speed drive affords considerable power and maintenance savings, compared to constant-speed drive, and the latter requires, also, time to operate its capacity control devices.

SIMPLE algebraic equations can be employed to calculate deceleration of the rotating parts of an induced-draft fan as soon as the driving power has been shut off, with the fan, however, continuing to operate in its regular system. The flywheel effect of the rotating parts is braked by the air delivery and wheel torque, plus journal friction. The braking effect of the journal friction is relatively insignificant until the wheel speed becomes very low. The tabulation shows the relation between the fan brake horsepower, and the journal friction horsepower. Wheel windage is included in the fan brake horsepower. Journal friction tends to produce a constant torque, whereas the fan horsepower torque and windage vary as the square of the fan revolutions per minute.

The tabulated WR^2 of the three typical induced-draft fans as made by the writer's company, includes the wheel, and its shaft. The WR^2 of a suitable hydraulic coupling runner is included merely to represent an average value for the rotating part of a variable-speed drive. The ratio of this to the WR^2 of the whole is very low, hence any nominal difference in the inertia effect of various variable-speed-drive rotors, should not affect the final results significantly. The data plotted here for deceleration do not account for any energizing from the drive during deceleration, as this is a study only of the effect of flywheel energy against the running output torque of the rotating parts of these induced-draft fans.

Acceleration-time curves are not plotted because here time is a function of the driver torque acceleration versus rotational WR^2, plus the square increase in torque, due to fan air delivery. The result is a matter of initial torque provision. Since this concerns the case of an induced-draft fan, the gas density and the system characteristic have to be assumed to remain unchanged during the period of deceleration. A change in gas temperature, for example, will change slightly the fan-wheel torque. On deceleration, the gas temperature is likely to decrease which increases the density of the gas, which, in turn, would slightly increase deceleration. The inertia effect of decreasing gas flow, likewise is ignored.

The approach to this method of calculation is to consider the mass of the rotor at rest, and to calculate its acceleration to full speed when a constant torque is applied. This is equal to the driving torque of the fan at full speed. Hence, with the above assumptions, if this constant torque, which is equal in value to the fan full-speed torque, is applied to brake the mass of the rotor, it is assumed the same time would elapse. In other words, acceleration time would equal deceleration time. The tabulation shows the time in seconds, required for the mass of three different induced-draft fan rotors, all selected and designed for the common duty shown.

The actual fan, however, would not behave in this manner because, as it decelerates, the air-brake torque falls off as the square of the revolutions per minute. There is an increasing gain of flywheel effect to continue rotation, against the air brake effect to slow down the fan wheel. With the above assumptions, theoretically the fan never would come to complete rest (with no journal friction) as there always would remain slightly more flywheel effect than air brake torque, at infinitesimal rpm. The calculation of such a function is a task employing calculus. This, however, can be approximated by setting up the equation, then calculating decrements, of say 10 rpm, from full speed down to a practical low speed limit. The derivation of the formulas is as follows:

Derived from $F = MA$, we have, for a rotating body;

$$T = IA \tag{1}$$

where
T = torque, in foot-pounds
I = moment of inertia
A = angular acceleration

$$I = \frac{WR^2}{32.2} \tag{2}$$

where
W = weight, in pounds
R = radius of gyration, in feet
32.2 = acceleration due to gravity, ft/sec/sec

$$A = \frac{w}{t} = \frac{2Pi\,N}{60t} \tag{3}$$

where
Pi = 3.1410
w = radians per second
t = time, in seconds
N = revolutions per minute

Substituting in (1), equations (2) and (3), we have

$$T = \frac{WR^2}{32.2} \times \frac{2Pi\,N}{60t} = \frac{WR^2N}{307.6t} \qquad (4)$$

Transposing equation (4), provides the equation for seconds time for deceleration, namely,

$$t = \frac{WR^2N}{307.6T} \qquad (5)$$

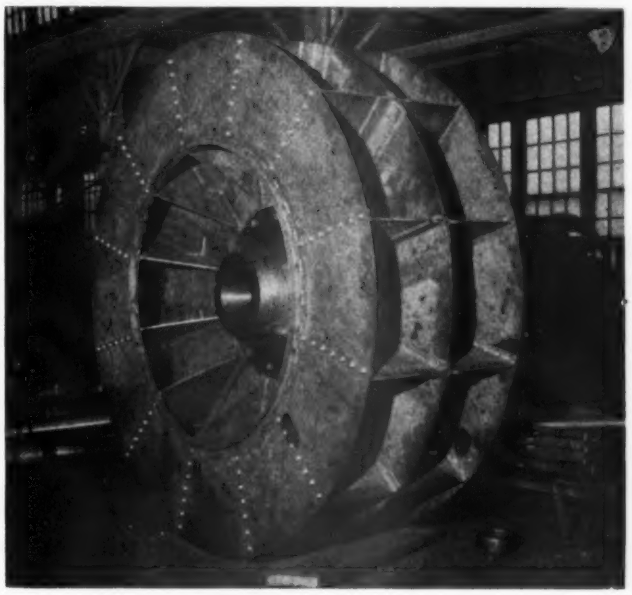
This equation calculates the time for constant torque and produces the seconds time shown in the tabulation.

Since the fan-braking torque varies as the square of the fan rpm, and since it is desired to calculate 10 rpm decrements, equation (5) becomes

$$t = \frac{WR^2dN}{307.6T(Ni/No)^2} \qquad (6)$$

where
dN = 10 rpm
Ni = average rpm of decrement
No = full fan speed, rpm

Thus for each wheel the tabulation provides values for all factors in equation (6) except Ni and t. Therefore, these



Radial-blade rotor

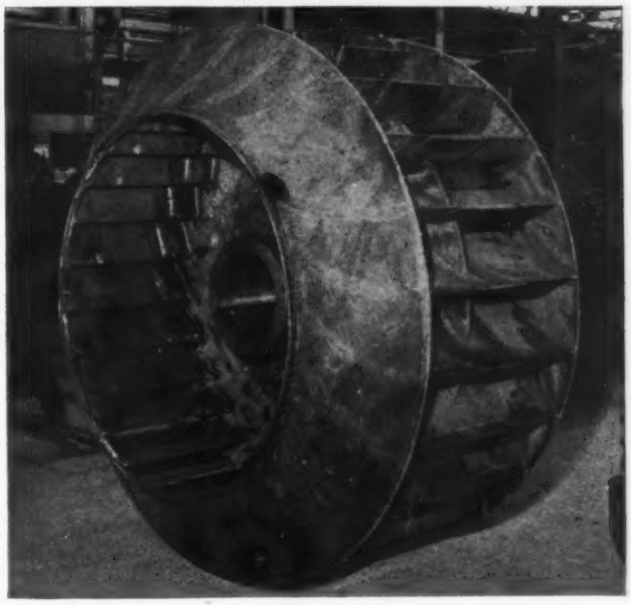
values become constants that can be substituted in equation (6) to form three equations, one for each of the three induced-draft fan wheels.

$72^5/_8$-in. wheel diameter, forward curve
$$t = \frac{0.0952}{(Ni/710)^2} \qquad (7)$$

87-in. wheel diameter, radial tip
$$t = \frac{0.2132}{(Ni/890)^2} \qquad (8)$$

142-in. wheel diameter, radial blade
$$t = \frac{0.667}{(Ni/505)^2} \qquad (9)$$

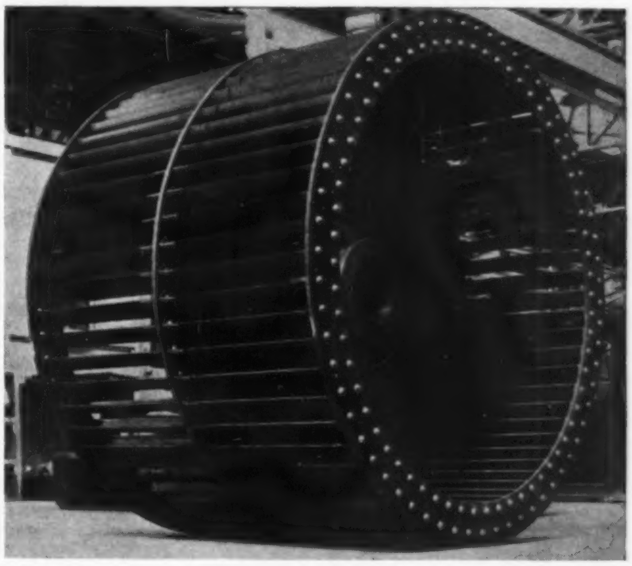
where
t = seconds for 10 rpm deceleration of these three specific forward-curve, radial-tip and radial-blade fan wheels, respectively, together with their shaft and proper size hydraulic coupling runner mounted on the fan shaft
Ni = average rpm in the decrement, which is taken other than the arithmetic average, to compensate closer for the slope of the curve



Radial-tip rotor

Each decremental time is added accumulatively to obtain the time intervals for 50 rpm. These values together with the corrected percent rpm are used to plot the curves to show the relation of the deceleration of these three types of wheels. They should agree with field observations except for minor errors caused by stack draft and internal hydraulic coupling windage to maintain rotation, versus journal friction to reduce rotation. These balance out in the case of the hydraulic-coupling drive to produce a minimum empty coupling fan speed of from 10 to 20 per cent of top fan speed, depending upon the amount of stack draft and the friction of the bearings.

A study of the family of curves illustrates another advantage of the forward-curve fan for induced-draft service, when variable-speed operation is employed. It possesses powerful "air brake" for deceleration in the upper half power range of the boiler. This has been known from experience for a number of years, but proba-



Forward-curve type

bly this is the first time such a direct comparison has been calculated and plotted. It represents the duty and size of one of two Sirocco induced-draft fans that have operated at top load continuously during the past year and

COMPARISON OF THREE INDUCED-DRAFT FANS

Duty.................285,000 cfm
S.P.......................$19^1/_4$ in.
Temperature.................350 F
$^1/_2$ outlet velocity pressure recovered

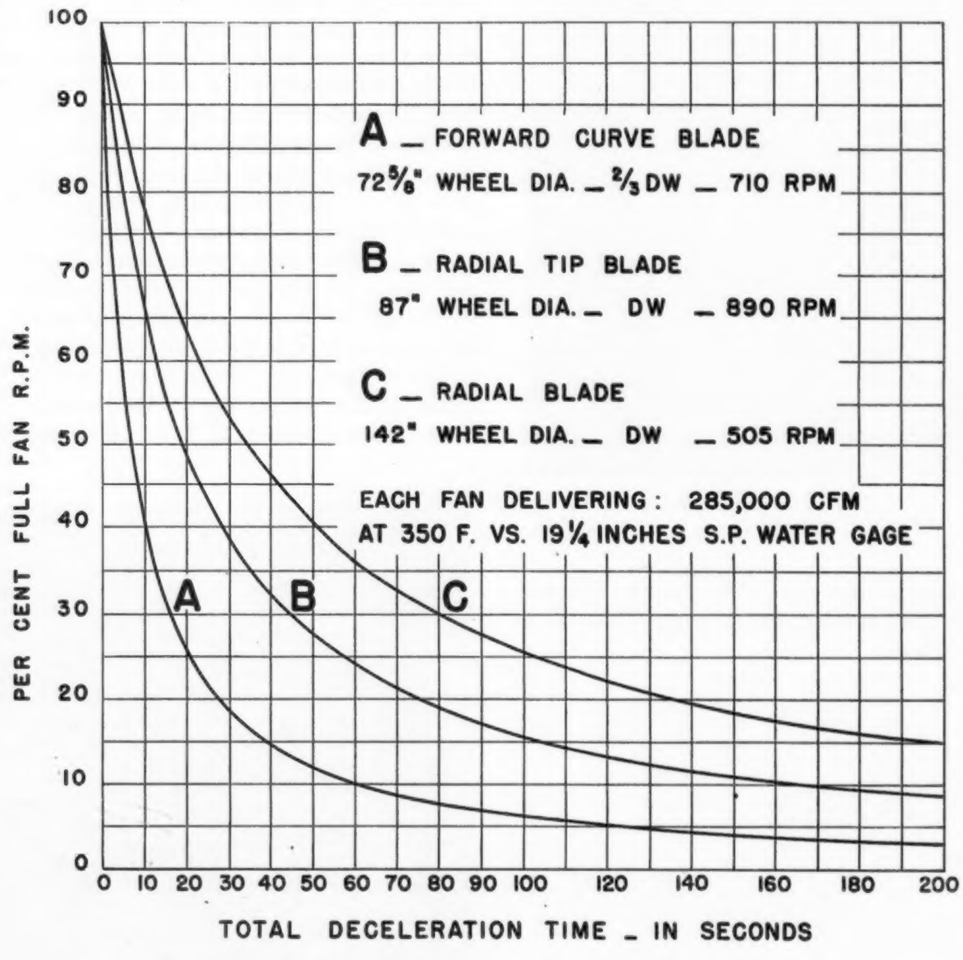
Type	Forward Curve	Radial Tip	Radial Blade
Wheel diam., in.	$72^5/_8$ (⅔DW)	87	142
Rpm	710	890	505
Bhp	1,218	1,300	1,260
WR^2, lb $(ft)^2$			
Wheel	24,570	48,500	265,000
Hydraulic coupling runner	1,450	930	2,950
Shaft	330	900	955
Total WR^2,	26,350	50,330	268,905
Full-speed torque, ft-lb	9,000	7,670	13,100
Journal friction H_p at full speed	1.5	3.1	2.9
WR^2 time to accelerate from rest to full speed, based on torque of full speed horsepower, sec	6.8	19.0	33.6

a half. The low WR^2 of this fan arises mainly from its lesser diameter, from which radius is squared; also this low WR^2 favors rapid acceleration from low speed. It is hastened by over-increasing the torque of the variable-speed transmission, meaning that the top speed full torque of the driving motor could become available to accelerate the fan wheel if it ever becomes necessary to make such a provision in the initial design of the equipment. This is available, of course, for any type of wheel, but the wheel's acceleration effect is greater for the low WR^2 rotating parts.

On the decelerating phase, the forward-curve fan requires only 28 sec to come down from top speed to 20 per cent, which is approximately 20 per cent boiler capacity. The radial tip fan requires 75 sec; or in 28 sec, it would reduce to 40 per cent speed. The radial blade fan requires 137 sec to reduce to 20 per cent speed; or in 28 sec, it would reduce to only 55 per cent speed.

There is a question as to what is the lowest boiler rating below which there is no value to rapid deceleration. This depends upon circumstances, but a good average probably lies between 20 per cent and 30 per cent boiler load.

Another question arises at top boiler load. If an automatic control system is adjusted to the very rapid boiler rating change cycle here illustrated, the question may be whether the boiler and its auxiliaries can take these quick changes without hunting.



Deceleration time of induced-draft fan rotors—flywheel energy vs gas braking torque with journal and minor factors neglected

Power Trains to Serve Military Needs in Devastated Regions Abroad

These brief notes on the 5000-kw and 1000-kw power trains were released through a recent meeting of the Metropolitan Section A.S.M.E. Further details and illustrations of the larger units will appear in the July issue.

A LARGE number of portable power plants on wheels, or so-called "power trains," in capacities of 1000, 3000 and 5000 kw, are now under construction in the United States for use of the armed forces of the United Nations or for restoring electric service in devastated reconquered areas. They will serve to make power available quickly anywhere that railroad tracks exist or can be laid. It is anticipated that they will find use in western Russia, North Africa, Italy and possibly China or any other localities as military operations advance; perhaps in central or western Europe. The large number under construction was dictated by these varied needs.

In such areas where electric power plants have been destroyed or put out of commission, power will be required by the occupying military authorities for hospitals, machine shops, repair shops, water supply and sewage systems and as replacement plants for certain other services. Mobile power plant capacity of ten per cent or less of that previously existing in a given area before devastation has been estimated as sufficient to meet such emergency demands.

Many special problems were involved in designing these power trains, such as ability to burn any kind of coal that may be available, particularly the poorer grades found in certain parts of Europe; complete independence of condensing water supply; ability to operate in sub-zero or torrid temperatures; and, in the case of the larger units, limitations of weight imposed by permissible axle loadings which abroad are less than in this country; and, finally, width and height of track clearances, here and abroad.

These power trains were the subject of a meeting of the Metropolitan Section, A.S.M.E. (New York) on May 17 at which the three speakers, as representatives of the principal companies supplying the power equipment for the 5000-kw and the 1000-kw units, discussed their respective phases of the work. They were C. M. Laffoon of Westinghouse Electric & Mfg. Company, who described the project in general and dealt with the electric generating features; Otto de Lorenzi of Combustion Engineering Company, who discussed the steam-generating units and firing equipment for the 5000-kw trains; and F. G. Ely of Babcock & Wilcox Company who dealt with the boilers for the 1000-kw trains.

Mr. Laffoon stated that his company is now building forty-five of the 1000-kw and ten of the 5000-kw trains. These are assembled in specially designed railway cars, with suitable trucks for transportation over railroads to points of shipment and for location on railway sidings, where needed, at which points they will be provided with supplementary foundation supports. The 5000-kw train consists of eight cars, namely, two for the steam-generating units, one for water, two for the air-cooled condensers and fans, one for the turbine-generator with its electrical equipment, one for auxiliaries and one for the crew. The 1000-kw train consists of three cars.

Under present war emergency conditions, Mr. Laffoon explained, the primary objective in designing and building electric-generating plants of this type, is to obtain the maximum output per unit of materials to meet actual operating conditions. The specification requirement that the generating plant be capable of being transported over railroads in a completely assembled condition necessitated that the cars be arranged in tandem and that the design be restricted, as previously mentioned, by height and width limitations, weight per axle, space in the cars and limited water supply for makeup and cooling. Hence, air-cooled surface condensers are employed to keep makeup to a minimum on the 5000-kw units and a conventional surface-type condenser is used in conjunction with a cooling tower on the 1000-kw units.

Stacks and ash hoppers will be detached during transit and set up when a train has reached its destination.

Several of the 5000-kw trains are already assembled and tests will shortly be completed.

Steam Generating Units

In describing the two steam-generating units for each of the 5000-kw trains, Mr. de Lorenzi stated that these are of the C-E two-drum, water-tube type, with water-cooled furnace, drainable superheater and Elesco fin-tube economizer, forced- and induced-draft fans; the complete unit being specially designed for low head room and in accordance with the other limitations mentioned. Each of the two units is rated at 40,000 lb of steam per hour at 625 psi and 750 F total steam temperature at the superheater outlet. Drum design pressure is 660 psi. The fully water-cooled furnace is an adaptation of locomotive design, employing a rear arch and is fired by a Standard spreader stoker of the type commonly employed in locomotive practice. The same applied to the grates which are of the Hulson type. Rated output was calculated on low-grade coal of approximately 7300 Btu per lb heating value and an ash-softening temperature of approximately 1800 F.

Mr. Ely stated that each 100-kw train has one 16,000-lb per hr B & W integral furnace type of boiler, of the two-drum bent-tube type with four-pass superheater, designed to operate at 420 psi and 725 F total steam temperature. It is fired by a Standard stoker serving a Hulson tuyère-type grate, such as is commonly used in locomotive practice.

*Necessity for Research on Combustion Rates and Ash Behavior**

By A. R. MUMFORD

Development Engineer, Combustion Engineering Company, Inc.

As timely problems in the field of fuel research, the author suggests (1) studies of the relation between hot-spot and average furnace heat releases to the end that higher combustion rates or less furnace volume may be possible, and (2) further studies on the behavior of ash to ameliorate present troubles. As a means of obtaining such information, the development of special means for measuring local conditions are advocated.

THE field of research in fuels is so large that it will be impossible, within the scope of this paper, to more than mention some of the problems concerned with higher rates of combustion. Higher rates of combustion would be beneficial if the reduction in furnace size and cost and in building volume were to offset the increased costs of operation. The present rates are set by the troubles encountered with ash and to a lesser extent the losses resulting from incomplete combustion. Overall performance figures have been of value but are no longer of great use in solving design problems because the relation of the average to the maximum is not known or not rationalized. We must know, for instance, how to conclude from the average temperature of the gases leaving a furnace and the furnace geometry what is the maximum temperature existing within the furnace cavity and the point at which it exists. Failures of pressure parts and troubles from intense heat release do not average out over an area or throughout a volume but only over a small part of the area or within a small part of the volume. The average condition is no more indicative of the maximum than the average wind velocity in a country is indicative of conditions in the heart of a cyclone within that country. We must, therefore, develop through research our technique of measurement to permit the advances in theory required before design can be improved.

Higher Rates of Combustion

Present methods of burning solid fuels on grates and in suspension, and of burning liquid fuels, clearly show differences in intensities which indicate that we are now burning fuels at rates in "hot spots" which if possible on the average would make the furnace volumes comparatively minute. Conversely, if the present averages were maintained and the variations between maximum and minimum rates were leveled out many of the existing "hot-spot" troubles would disappear.

* A paper before the Midwest Power Conference, Chicago, April 13–14, 1944.

The writer has made tests of boilers fired by pulverized coal in water-cooled furnaces in which average heat release rates of 25,000 to 30,000 Btu per cu ft per hr were easily obtained and maintained. Similarly, tests of boilers with small refractory-lined furnaces fired with oil have been made just as readily with average heat release rates of 175,000 Btu per cu ft per hr. Rumors of tests involving release rates with oil fuel over twice this latter value have been heard, and direct-fired air heaters using oil have been reported as burning millions of Btu per cubic foot. Tests made by the writer on Coxe stokers burning anthracite have shown it possible to sustain rates of combustion as high as 50 lb per sq ft of grate per hour, equivalent to 150 lb or 1,700,000 Btu fired per cu ft of fuel bed per hour. Not all of this heat was released in the bed, the analyses of the gases at the top of the fuel bed showed that some was released by gaseous combustion within the furnace. Considering the fuel bed as a gas producer, producing a gas rich in CO, we can assume that this value should be reduced to about 850,000 Btu per cu ft of fuel bed per hour.

The point is that very high rates of combustion are readily obtained with liquid fuels not associated with ash and in beds of solid fuel not disrupted by air flow. The almost fantastically high figures estimated for fuel bed release rates suggest a "hot spot" to average ratio of thirty or forty to one which makes one question the significance of the corresponding average value for the entire furnace. Few data are available on the variation in the intensity of combustion in the furnace cavity but no one will deny that large variations exist and, therefore, the average does not indicate the maximum. The aim should be to find what conditions exist at the "hot spot" in the furnace and how we may increase the volume of the "hot spot" until it fills the furnace; and thus bring the average rate of heat release to at least the value which exists at some point in the furnace today or, conversely, how indicated maximum intensity may be brought down while keeping the average the same.

Part of the problem of higher rates of combustion or the elimination of "hot spots" is the effective use of the available furnace volume. In marine boiler tests it has been found that the rotary motion imparted to the air by registers on oil burners was dissipated very quickly in rectangular furnaces but persisted in the cylindrical furnaces of a Scotch marine boiler. From this, and other indications, it can be concluded that the shape of a furnace has an important influence on the effectiveness of mixing. It is fair to assume, from available observations, that some shapes of furnace permit the formation of more eddy currents than others and the initial energy of the fuel and air streams is dissipated by these eddy currents. Furnaces are now shaped to fit available space and to comply with certain obvious requirements of

practical and economic construction. From considerations of the change of kinematic viscosity of gases with temperature it seems likely that we must be prepared to use energy much more freely in large furnaces to secure the same degree of turbulence as is now obtained in small furnaces. This relation of the factors controlling the ability to secure thorough mixing of the fuel and air for combustion is at present entirely on an empirical basis and should be rationalized by research.

Oil fuels are being burned in furnaces under pressures of five or six inches of water quite generally and we may learn, after the war, that pressures measured in pounds have been used, as is the case in the Velox boiler. Increasing the number of oxygen molecules within a given volume by increasing the furnace pressure ought to increase the opportunity of collision with fuel particles and, therefore, the intensity of combustion. The answer may be partly known and may be made available later; but even though the answer has been found for liquid or gaseous fuels its application to solid fuels will probably be subject to modification because of the ash content.

The British Coal Utilization Research Association in its report on the "First Five Years" states that "By measuring the energy of its interaction with methyl alcohol it was established that coal substance is so finely structured that the surface accessible to oxygen molecules ranges from 100,000 to more than a million square feet per pound according to its rank." This seems large but it is probably small if compared to well-atomized oil. The problem, therefore, is not essentially one of providing contact surface in the fuel but of utilizing more effectively the contact surface provided by nature. The more effective utilization of this contact surface may come about by crowding more oxygen molecules into the small spaces; that is, by increasing pressures in the combustion chamber. The extra cost of the structural changes necessary to resist these pressures will be at least partly offset by the decreased size of the furnace. At any rate, full-scale experiments are not economically feasible and small-scale laboratory work should be undertaken.

Loss in Reactivity with Anthracite

Those who have burned anthracite have been interested in, and perhaps annoyed by, the particles carried out of the furnace in suspension in the gases. Some of us have tried to burn these particles and found it difficult. The above-mentioned report points out that "The marked decay in reactivity shown by anthracite when heated had been investigated. This property renders the relighting of partly consumed anthracite peculiarly difficult. The effect was traced to a loss of 'inner' surface (accessible to oxygen) when the fuel is heated above 800 C." If the reactivity of the unconsumed portion of a solid fuel decreases during the burning progress, what is the extent of the decrease and what factors affect it? It seems reasonable to expect some decay in reactivity of the fuel as it burns because the most reactive portion would naturally be the first consumed. Some change of this character may account for the necessity of assigning a large part of the volumes of existing furnaces to the combustion of the last portions of solid combustible in comparatively quiescent zones. In such zones mixing action is at a minimum and probably the reactivity is low, both factors working against the reduction in furnace volume. Perhaps when measurements of reactivity are made on representative samples of the fuel in the progress of its combustion it will be possible to apply energy for mixing as needed and thus maintain "hot spot" burning rates in what are now quiescent zones of the furnace.

In any consideration of combustion in fuel beds a very obvious point is that the fuel is in large enough particles so that it is not floated on the air stream. Under such conditions the scrubbing action of the air against the surface of the incandescent fuel is a maximum and reaction is rapid. Much work on fuel beds has been done. Henry Kreisinger did some pioneer work at the Bureau of Mines on combustion in fuel beds and pointed out that all oxygen would be consumed from the air passing through a bed of incandescent fuel four inches or more in thickness. The significance of this work on fuel beds is that it is theoretically and practically impossible to supply sufficient air for combustion through those sections of the fuel bed composed of a thickness of four inches or more of uniform incandescent fuel. Obviously, the deficiency in air must be made up through other portions of the fuel bed which are not completely ignited or which are burned out. The streams of gases deficient in oxygen must be mixed with those rich in oxygen either by providing time and volume enough for diffusion, or by compulsion in the form of arches. Arches can work perfectly only at the rate of combustion or flow of gases for which they are designed. At other rates some assistance must be given in the form of steam or air jets to provide the mixing.

Jets vs Arches

In 1924 the writer reported a study of "Combustion of Anthracite on Coxe Stokers" in which steam jets were used to simulate the action of a rear arch. The results, using steam at 150 psi, were approached but not equalled by the arch. If air jets are used the air must have sufficient energy to penetrate the gas streams and supply the needed oxygen. The spur for research along the lines of combustion in fuel beds is the high volumetric heat release rates obtainable in fuel beds and the comparative ease with which high release rates may be obtained in the combustion of the gases rising from the bed. The desirable condition is the maximum turbulence of the air and gases passing through the fuel bed, obtainable without disruption of the bed, together with energetic mixing devices and air supply in the furnace above the grates to insure rapid gaseous combustion. Perhaps some combination of combustion on grates, in suspension, and gaseous combustion will be indicated as the most economically efficient use of available volumes.

Radiant Heat Absorption

In the study of combustion with emphasis on the factors affecting higher rates, the rate of loss of heat from the flame is of importance. Most large units are designed with some arrangement of water cooling at the envelope of the furnace and this cold surface absorbs heat as a function largely of the emission temperature and the black-body volume of the flame. Except in furnaces having a high degree of turbulence the convective component of absorption is small. At present it is quite generally the practice in estimating the emission temperature of furnaces gases to assume it to be the same as

the average temperature of the gases leaving the furnace cavity. This assumption is safe enough for a furnace which does not approach limiting conditions at the "hot spot," but is questionable when it is known that wide variations exist within the furnace cavity and that the maximum may subject the cooling means at some point in the envelope to a strain beyond its limits. Here again, the relation of the temperature of gases leaving a furnace to the emission temperature of the gases within the furnace should be studied with emphasis on the maxima and measuring devices are needed. John Blizard pointed out in his recent paper on "Absorption of Heat by the Walls of a Furnace" before the A.S.M.E., that the amount of heat absorbed in a cooled furnace was found to be related to the rate of firing. Under his conditions most of the heat was transmitted by radiation and his findings are of interest, in indicating that the black-body volume of the flame changes with the rate of fuel consumption. Temperatures of the flame, at the different rates, varied somewhat because of minor variations in CO_2 but not sufficiently nor consistently enough to explain the variations in the quantity of heat absorbed. Although the trend in large utility units seems to be toward operation at nearly constant loads, a sufficiently large number of units will be needed for operation at varying loads to make the determination of the relation of black-body volume of flame to fuel consumed and to furnace geometry an important research project.

Cooling the Furnace Envelope

If research rationalizes the manner in which higher liberation rates may be obtained, as well as more effective use of available volumes, it must also solve some related problems having to do with the design and cooling of the furnace envelope. Paradoxically, the liquid phase of water has been shown to be less effective as a cooling medium than the mixture of liquid and vapor phases at a slightly higher temperature. Work on the transmission of heat to boiler tubing at high pressures[1] reported the empirical conclusion that the film resistance under evaporating conditions was negligible as compared with the resistance of the metal of the tube; but in the absence of vapor the film resistance was found to be appreciable. The low film resistance is believed to depend on the disruption of the liquid film during the formation and escape of vapor bubbles. Assuming the relative unimportance of the film resistance under evaporating conditions as compared to the resistance of the metal of the tube Dr. Jacob, in a discussion of this paper, computed the tube surface temperatures at certain rates of heat absorption and thus confirmed the conclusion.

Assuming, then, that the furnace cavity will be cooled by evaporation, how can the resistance due to tube wall thickness be reduced, particularly at high pressures other than by decreasing the tube diameter? In long small tubes, as are practicable in forced-circulation boilers, the sum of the radiation and convection components in a furnace having an extreme degree of turbulence and a high rate of heat release may produce tube surface temperatures 150 F above saturation. Ely and Schueler[2] have reported the failure of a thick wall tube due to temperature stresses alone even with adequate circulation of the cooling medium. This indicated that, at that location, the stress produced by the temperature differential through the metal exceeded the resistance of the metal to stress and the rate of heat transmission had to be decreased. What are the temperature drops through available alloys and what is the relation of these drops to those found for carbon steel of the same strength? As operating pressures approach the critical it is apparent that the amount of heating surface devoted to evaporation will decrease and the proportion devoted to water heating and superheating will increase. At the critical pressure no evaporating surface is required because of the absence of latent heat and the boiler will then consist of a water heater and a superheater. It should be an interesting problem to determine the disposition of heating surface so that the change in the cleanliness factor of the furnace will not upset the designed balance of the heating surface or will not completely preclude operation at more than one load. The amount and distribution of the heating surface must be based on a knowledge of the rate at which heat is released and available as well as the mechanism by which it is transmitted to the liquid. At low steam pressures, the ability of a tube to absorb heat was seldom, if ever, questioned but now we need to know more of the limits of such absorption because they are being approached.

Ash Behavior

It is generally recognized that ash is always a nuisance and sometimes constitutes an operating problem. The degree of the nuisance or problem differs with the quantity or the physical properties of the ash and sometimes with both. The ashless fuels, oil and gas, do not constitute a sufficiently large proportion of our fuel reserves to warrant any optimism that they will remove, by substitution, the obstacle that ash now constitutes in obtaining higher rates of combustion. Furthermore, 75 per cent of our solid fuel resources are in the central and western fields which are likely to contain appreciably more non-combustible material than the eastern. It seems obvious that any problems introduced into the burning process by the presence of non-combustible material are likely to increase as our resources decrease. For this reason and because the ash in coal is now much more of a problem than an annoyance, research should be directed toward its amelioration.

The two principal problems introduced into the combustion of solid fuels by ash are the insulation of heat-absorbing surfaces and the obstruction of gas passages. Heat-absorbing surfaces are insulated by the adherence of particles of ash that form a layer varying in thickness in accordance with the physical properties of the ash. The more refractory the ash the less the trouble to be expected, assuming that the present laboratory measurements of softening and fluid temperatures are indicative of the viscosities involved. The result of this insulation is to disturb the design balance between evaporating and superheating surfaces and this necessitates changes in operating procedure to restore the desired conditions.

[1] "Studies of Heat Transmission Through Boiler Tubing at Pressures from 500 to 3300 Pounds," by P. H. Hardie, C. G. R. Humphreys, A. A. Markson, A. R. Mumford and T. Ravese, A.S.M.E. *Transactions*, August 1943.

[2] "Distribution of Heat Absorption and Factors Affecting the Performance of the Twin Branch 2500-psi, 940-F Boiler with Reheat to 900 F," by E. G. Ely and L. B. Schueler, A.S.M.E. Annual Meeting, December 1943.

When the layer of ash deposits on adjacent boiler tubes between which the gases are flowing, the layer may build to a thickness which will materially increase the draft loss or completely obstruct the flow thus necessitating reduction of rating until the obstructions are removed. Minor problems are introduced by the variation of the relation between viscosity and temperature affecting the removal of ash as a fluid from furnaces.

Ash also has some chemical properties. We believe that the chemical properties of the ash are responsible for the loss of metal from furnace tubes under the conditions of gas composition existing in parts of the furnace. This particular reaction is being studied in the laboratories of the Bureau of Mines in Pittsburgh under a cooperative agreement. When this investigation reveals the fundamental reactions involved, the control of the reactions will be apparent.

Relating Laboratory Measurements to Field Conditions

The pioneers in the field of ash softening, fusion and liquid temperatures are today in the forefront of those recognizing the need for new studies of the physical properties of ash. Much work has been done but more is necessary to relate laboratory measurements to field conditions. At present certain physical properties can be predicted from a knowledge of the chemical composition of the ash but until more is known of the actual conditions to which the ash is exposed in the furnace the greater part of the value of this information will remain potential. If, however, the conditions of exposure are determined and related to the geometry of the furnace and the firing rate and method, it is not too optimistic a prediction to say that it should be possible to estimate the location and thickness of deposits and infer the resultant effect on heat transfer from our knowledge of the black-body volume and the emission temperature of the flame and the physical properties of the ash. There is uncertainty at this time whether the conductivity of slag varies with its chemical composition, but a study of this property is under way at the Bureau of Mines under the above-mentioned cooperative agreement. The results of this study will indicate whether chemical composition can be eliminated from consideration in determining the insulating effect of the layer of slag and hence consider only its thickness and its particular physical structure.

The effect of physical structure will be studied by relating the laboratory results to field conditions. The thickness of the deposit will obviously vary with the conductivity of the ash, thus an ash having a high resistance to the flow of heat will become fluid at the surface in comparatively thin layers. To relate the laboratory work to field conditions the heat flow must be measured by existing temperature drop methods and instruments developed to measure the furnace side surface temperature of the slag layer. Without a more complete knowledge of the physical properties of ash any attempt at eliminating it, as one of the factors preventing the attainment of higher rates of combustion, must be almost entirely empirical and probably costly. With more knowledge the designer can make some provision in his design to fit it to the predicted conditions for the case under consideration.

It is known that the combustible substance of coal is, in general, less dense than the non-combustible substance. Separations have been made by flotation and the heavier fractions found to contain the larger proportions of non-combustible material. Coal washing is practiced at some mines but only where the ash content of the original product was considerably higher and more troublesome than that of competing coals. Some users have justified the cost of cleaning by reduction of operating costs in existing installations. There is evidence also that the cost of cleaning is not justified when the furnace can be designed to handle the uncleaned fuel. At any rate more knowledge of the properties of the ash will permit the formation of conclusions with greater assurance.

Conclusion

The writer has endeavored to point out the necessity for fuel research and the lines it might take. To accomplish two general objectives, (1) increasing the combustion rates and (2) amelioration of troubles from ash, we must develop and use instruments to measure local conditions within the furnace cavity or fuel bed, and the physical and chemical properties of the ash. We should no longer predicate extrapolated performance on existing average conditions but should study the maxima in detail. Dr. Carl B. Boyer in his *History of the Measurement of Heat* said "As science goes on in the search for still greater unity, let it be remembered that the way is paved, not with unmeasured speculation, but with the objective data of patient quantitative research."

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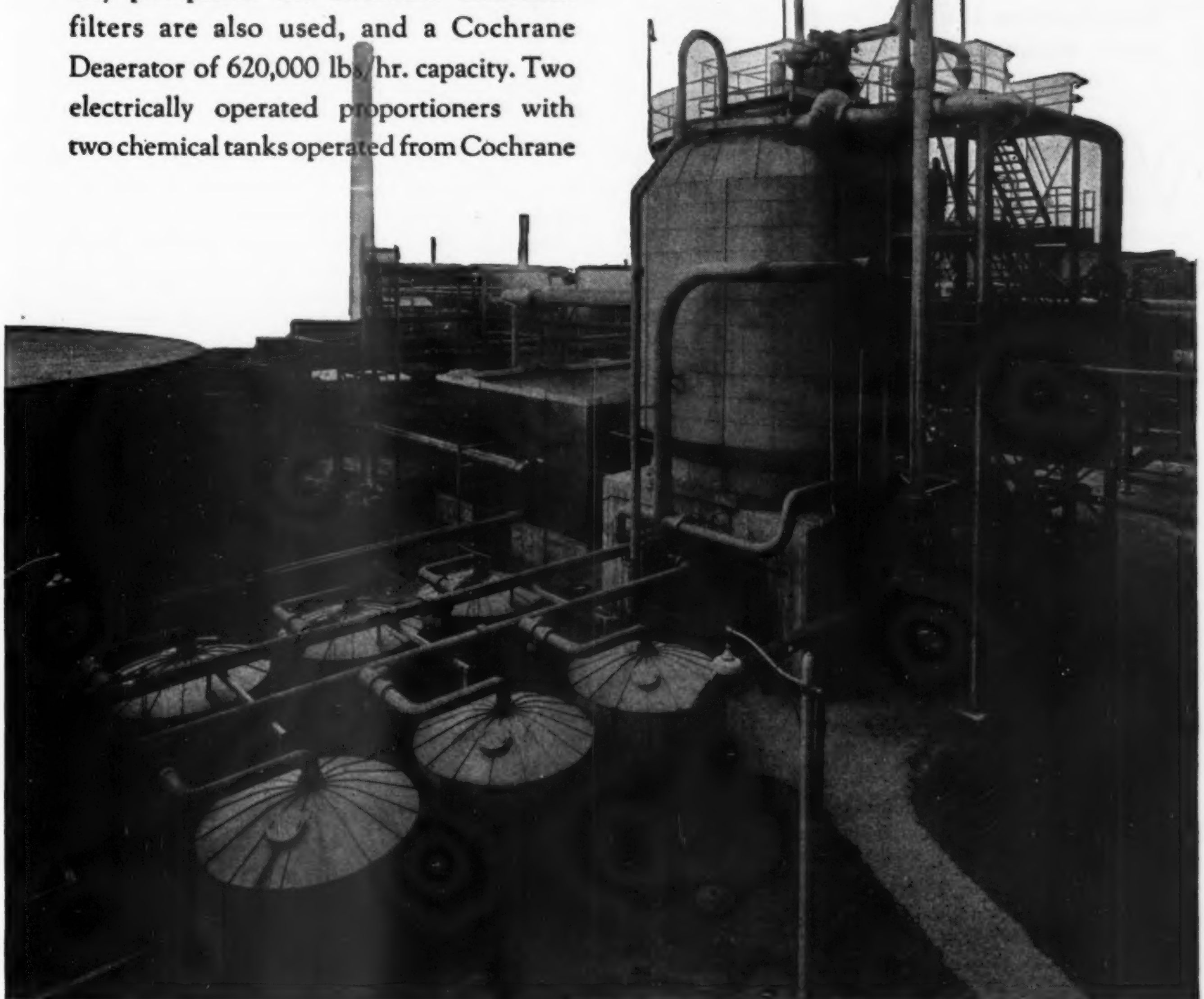
Complete details of this and many other modern boiler plant installations will be furnished on request.



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High-Pressure and High-Temperature Steam for Marine Use

The following discussion before a meeting of the Metropolitan Section, Society of Naval Architects and Marine Engineers, on April 28, 1944, reviews advances in marine steam generation with particular reference to forced circulation, several designs being shown of such boilers that are in actual service.

By W. H. ARMACOST, Vice President
Combustion Engineering Company, Inc.

WITHIN the past decade marine boiler designs have undergone a pronounced development. Perhaps this change would have been even more notable if not affected by the mass-production program of the Navy and the Maritime Commission. However, it is anticipated that post-war competitive shipping conditions will witness a continuation, even an acceleration, of such improvements in marine boilers for better economy of ship propulsion. In this trend higher pressures and temperatures are sure to play a leading role.

Marine boilers for the generation of steam at high pressure and temperature have always been of major interest due to the inherent savings possible. The designs developed in this field are based on a background extending back to the shipbuilding program of World War I and reflected in a wide participation in the present shipbuilding programs of the Maritime Commission and the Navy, and enhanced by a broad experience in this field in stationary work.

Generation of steam at present high pressures and temperatures can no longer be considered experimental. Reliability is a matter of perfection in detail of design, manufacture, and erection rather than of the type of plant. Any consideration of high-temperature and high-pressure steam should receive due concern with respect to turbines, to auxiliaries, and to water treatment, as well as to the boilers. Progress in the development of these equipments has kept in step to a surprising degree. Although at times one may have progressed more rapidly than another, any tendency to lag has been quickly overcome.

As a result we find today in turbines, auxiliaries and boilers tried and proved designs from all standpoints. This is true of materials, methods of construction, capacities and methods of operation. Many lessons learned in shore plants are directly applicable to shipboard plants. Materials suitable for sustained operation at temperatures of at least 950 F are well known, and it is anticipated that alloys suitable for even higher temperatures will be available in the near future. The adoption of welding has been widespread especially as applied to boiler drums and steam piping. Knowledge has been gained to allow provision of proper thicknesses of tubes and drums without setting up excessive stresses arising out of differential expansion associated with high rates of heat absorption. Feedwater treatment aboard ship is simplified due to low distilled makeup required.

The accompanying illustrations show a range of recent designs.

The boilers shown in Fig. 1 are installed in large combination passenger and cargo ships. There are four per ship, each having a normal capacity of 40,000 lb of steam per hour at 600 psi gage and 840 F.

Fig. 2 duplicates in nearly all respects that shown in Fig. 1, except the shape of the furnace is modified to fit a differently shaped fire room space.

Fig. 3 and the one following are designs brought out about five or six years ago. It was designed for 1215 psi and 750 F at the superheater outlet, and a capacity of 32,000 lb of steam per hour. The efficiency is about 86 per cent. The separately fired furnace is to provide controlled reheat.

The design in Fig. 4 was developed at about the same time as that in Fig. 3 and was designed to generate 31,000 lb of steam per hour at 1300 psi and 960 F at the superheater outlet. The feedwater temperature is 400 F and the efficiency 88 per cent.

A number of boilers of the type shown in Fig. 5 are now under construction and are to be installed shortly in new ships. The design pressure is 1535 psi, for operation at 1460 psi and 750 F. The capacity is 50,000 lb of steam per hour. This provides also for two stages of steam reheat. Its features are as simple as for lower pressures, showing that higher pressure and temperature can be used without additional complication.

The following table is based upon R. H. Tingey's paper, on "High-Pressure Steam for Marine Propulsion," presented last October before the New England Association of Naval Architects and Marine Engineers.[1] It indicates the magnitude of the gains that may be achieved with pressures up to 1450 psi and temperatures up to 950 F.

Pressure and Temp.	Approx. Per Cent Fuel Reduction
450–750	0
600–850	6
900–900	10
1450–950	13
1450–750 (1 steam reheat)	9
(2 steam reheat)	11
1450–750 (1 gas reheat)	11

Additional gains of lesser magnitude may be secured by temperatures and pressures higher than 1450 psi and 950 F, but higher pressures will require boilers of greater height, perhaps in many cases more than can be afforded by the naval architect, if the natural circulation boiler is adhered to. Otherwise, the obvious difficulties due to

[1] Reprinted in the January and February 1944 issues of COMBUSTION.

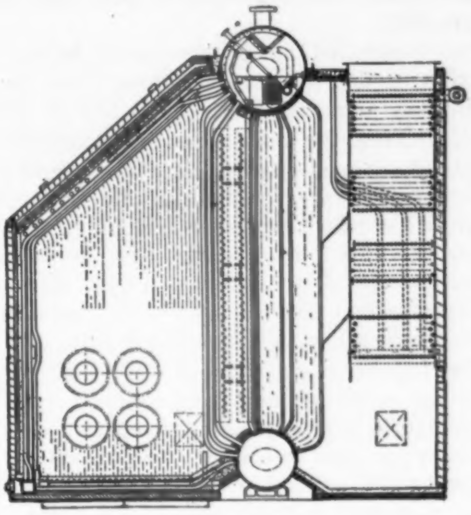


Fig. 1

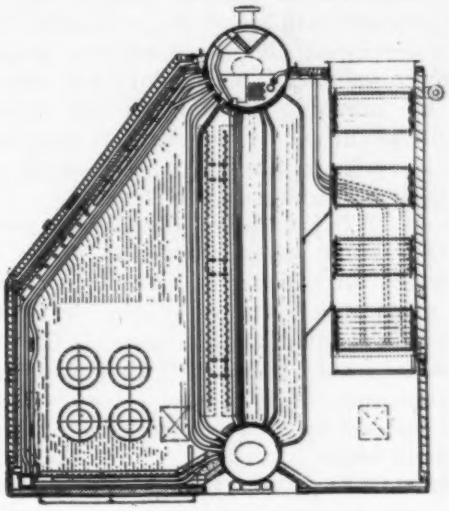


Fig. 2

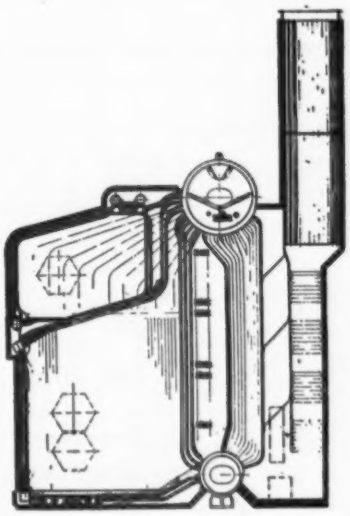


Fig. 3

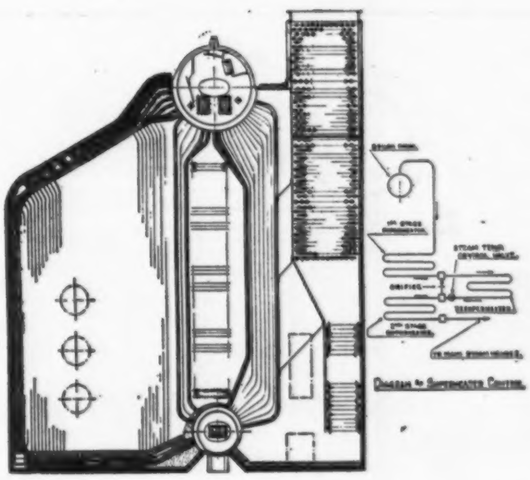


Fig. 4

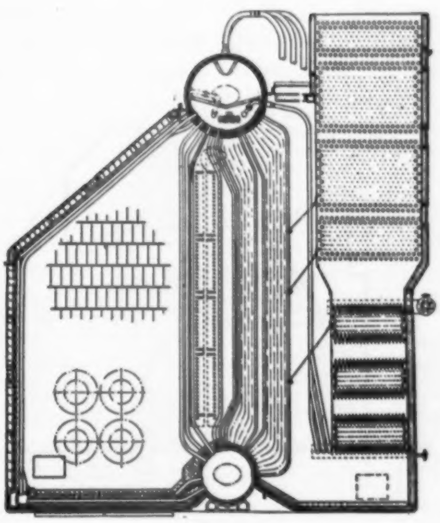


Fig. 5

SOME RECENT DESIGNS OF NATURAL CIRCULATION MARINE BOILERS

inadequate circulation will arise. Such handicaps may, however, be overcome by the forced-circulation boiler. Higher temperatures will await the availability of the suitable war-developed alloys, information respecting which is now obtainable. Such alloys will also be a product of the intensive development now being expended on the gas turbine. Thus, it is felt improvement in gas-turbine cycles will result in corresponding improvement in steam-turbine cycles.

Up to about 1500 psi, boiler construction does not depart radically from previous practice. Tube banks may be arranged for satisfactory heat absorption and still permit drum tube plates of reasonable thickness. Above 1500 psi, complications arise with thick tube plates, or on the other hand, wide tube spacing and lower heat absorption must be used. Under 1500 psi, conventional natural-circulation designs are adequate to meet the problems presented. The ratio of the density of water with respect to the density of steam measures the rate of circulation in a natural-circulation boiler. Above 1500 psi this ratio decreases very rapidly. Thus, higher boilers are necessary to provide enough "head" for sufficient circulation to prevent damage to tubes subjected to high rates of heat absorption. Under most conditions aboard ship, such height is unobtainable.

The controlled forced-circulation boiler is a simple solution to this problem. Through the use of positive circulation extremely wide flexibility of design is possible, making the boilers readily adaptable to limited and oddly shaped spaces. It also permits arrangement of heating surfaces to best advantage. Operation of controlled forced-circulation boilers, like natural circulation, does not require intricate controls. Furthermore, the forced-circulation principle allows the boilers to be put on and taken off the line very rapidly. Extreme load changes affect water level very little.

The following illustrations show the application of forced-circulation boilers over a wide range of pressures, temperatures and capacities, from as low as 20,000 lb of steam per hour to 650,000 lb of steam per hour, from 290 psi to 2000 psi and from 690 F to 950 F.

Fig. 6 represents a controlled forced-circulation boiler having a capacity of 120,000 lb of steam per hour at 290 psi and 690 F. It is included merely to indicate the complete range of temperature, pressure, and type of service to

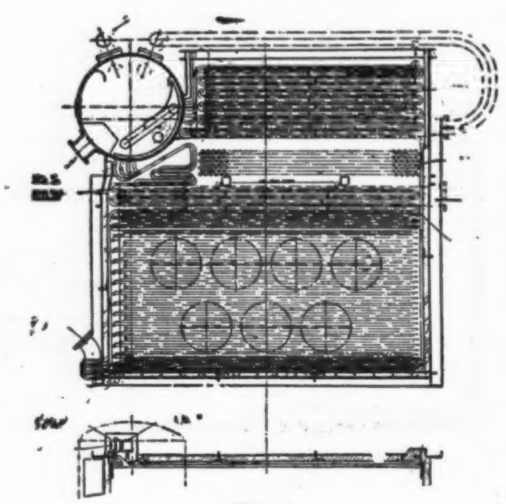


Fig. 6

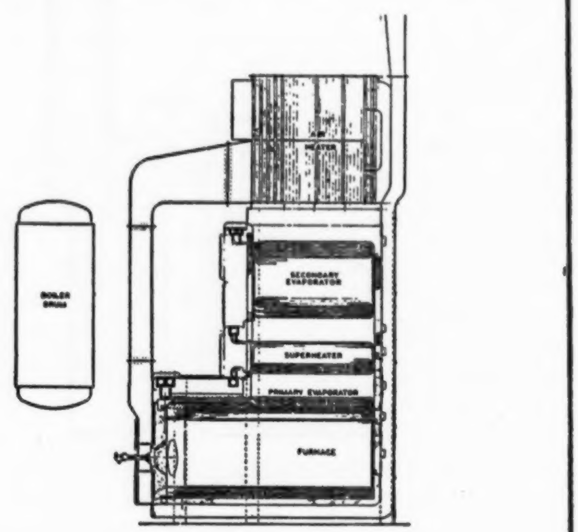


Fig. 7

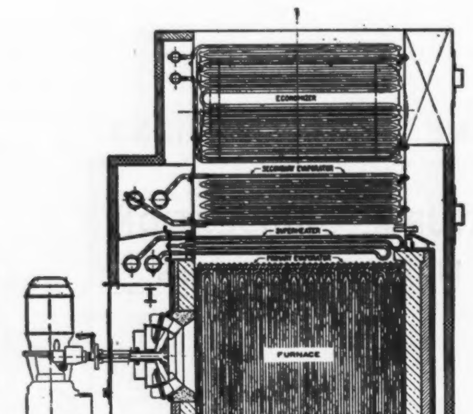


Fig. 8

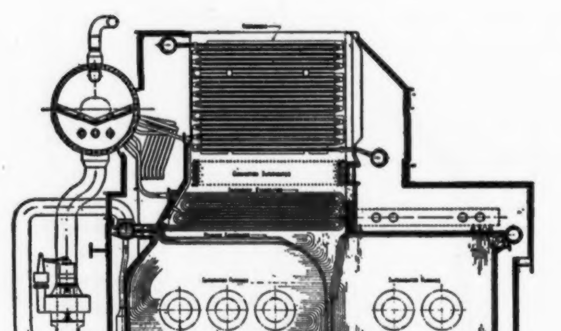


Fig. 9

CONTROLLED FORCED-CIRCULATION MARINE BOILERS FOR WIDE RANGE IN PRESSURE

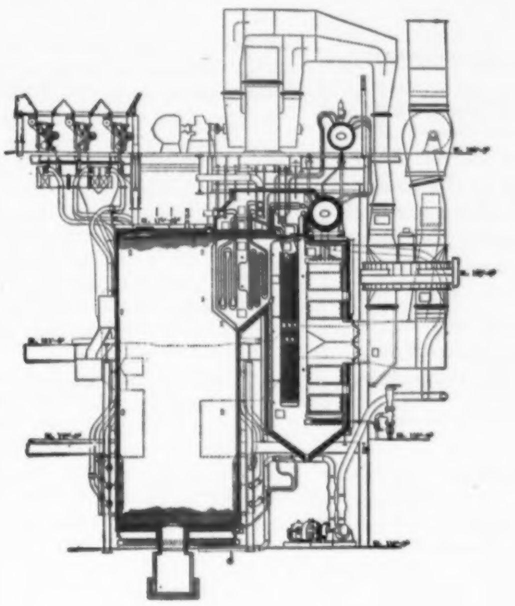


Fig. 10

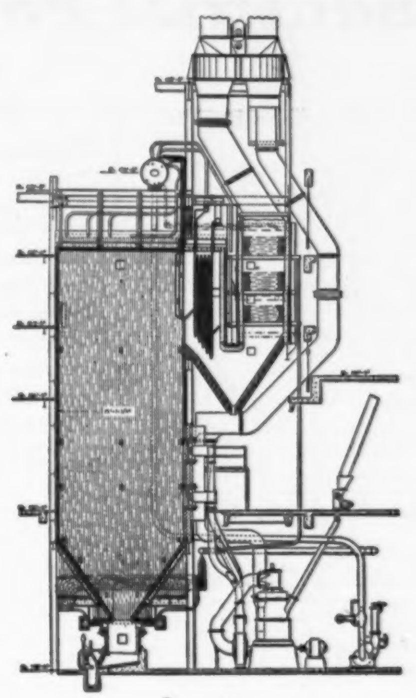


Fig. 11

TWO LARGE FORCED-CIRCULATION UNITS INSTALLED IN STATIONARY PLANTS

which controlled forced-circulation boilers are applicable.

The boiler in Fig. 7 is designed to operate at 500 psi, with a steam temperature of 800 F and is shown to indicate the flexibility in design when forced circulation is used. The capacity is approximately 26,500 lb per hour. This unit has been operating satisfactorily over a period of several years.

Fig. 8 shows a controlled forced-circulation boiler specially designed to fit into an extremely restricted fire room space. The capacity is about 20,000 lb of steam per hour at 900 psi and 850 F.

Fig. 9 represents another special design of forced-circulation boiler for 1200 psi and 900 F with a separately fired superheater for complete control of superheat. The maximum capacity is in excess of 200,000 lb of steam per hour.

Fig. 10 shows a large unit which operates at a capacity of 400,000 lb of steam per hour at 700 psi and 750 F, and Fig. 11 is a unit operating at 1825 psi (2000 lb design) and 960 F. It has a capacity of 650,000 lb of steam per hour. These last two are installed in stationary plants and are included merely to show the present range in capacities of forced-circulation units.

All of these forced-circulation boilers have been built and are in operation.

Following the present period of restrictions on the use of materials there is a feeling in some quarters that extensive use in shipbuilding will be made of lightweight metals and alloys. When this develops, the weight of the boiler begins to assume a new importance. Forced-circulation boilers can be made lighter than natural-circulation boilers, particularly where higher steam pressures are involved.

Industrial Power Requirements

A COMPREHENSIVE report has just been issued by the Federal Power Commission dealing with "Electric Power Requirements of Industrial Establishments." Actual figures are given for the period 1939–1942, inclusive, which are extended to 1944, based on estimates reported for over 90 per cent of all electricity consumed by manufacturing and extracting industries in the United States as well as government-owned establishments, such as arsenals, etc. The term "extracting industries" is applied to mining of all kinds, petroleum and natural gas. Of the total of 21,235 establishments reporting for 1943 the estimated electric requirements were nearly 156 billion kilowatt-hours divided as follows:

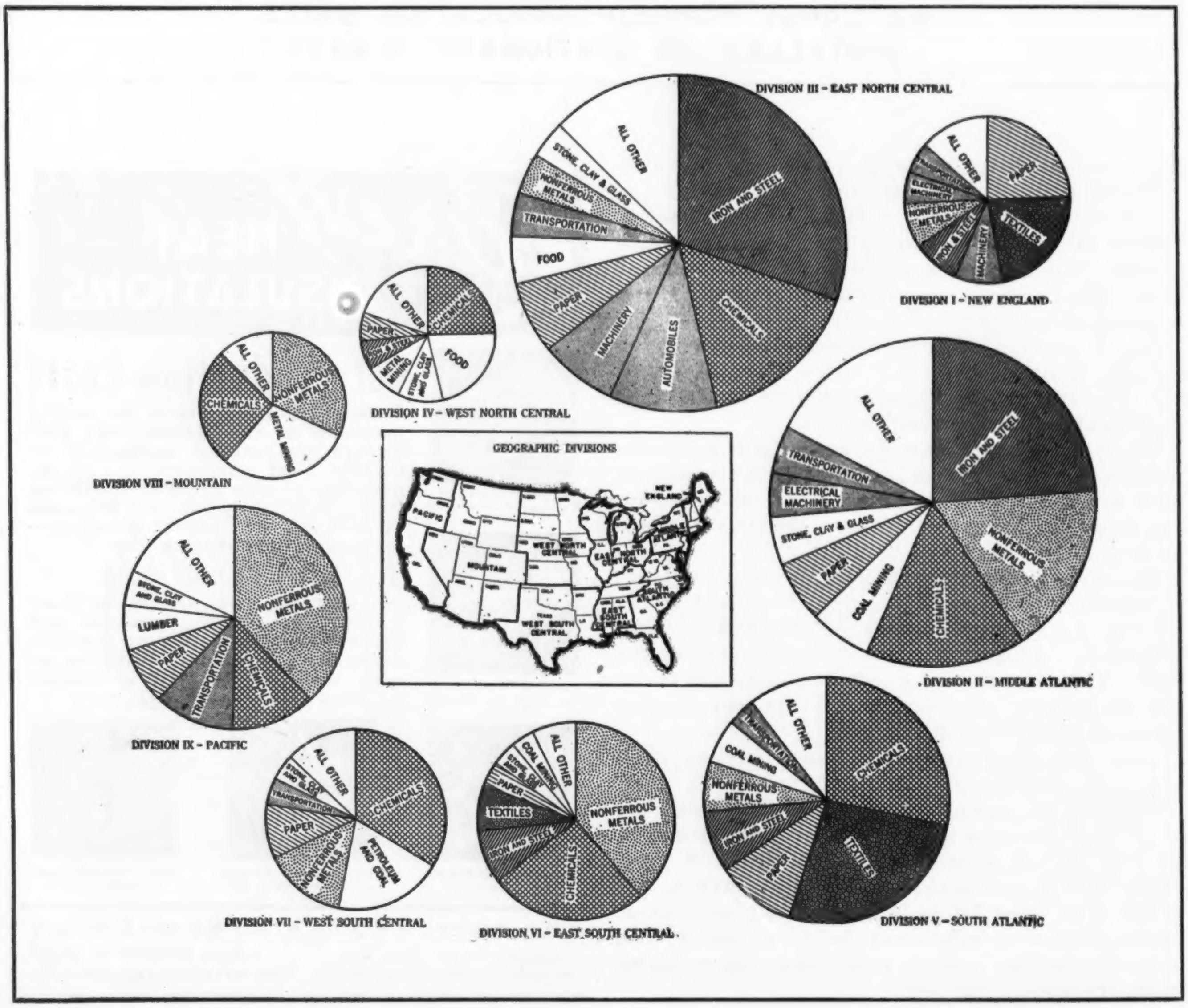
Classification	Electricity Requirements of Reporting Establishments, 1943 (Thousands of Kilowatt-hours)	Number of Reporting Establishments
Manufacturing	141,491,569	18,475
Extracting	9,149,642	2,399
Government	5,306,903	361
Total	155,948,114	21,235

Figures for 1939–1942, extended to 1944 and covering over 21,000 reporting establishments, show that industrial use of electricity has more than doubled during the last five years. Of this, purchased electricity increased nearly three times and that privately generated was up 66 per cent. Load factors were considerably higher for the latter.

The reporting establishments are classified in accordance with the 1939 Census of Manufacturers; that is, on the basis of the principal products manufactured during peacetime. Although considerable conversion of industrial production has taken place since this country entered the war, this has applied largely to products rather than to the particular industry, so that reclassification into other groups has not been necessary. The chief exception has been the automobile industry which is now engaged extensively in making aviation products; although it is still turning out much automotive equipment such as trucks, jeeps, armored cars and tanks.

Table 1 represents electricity requirements of reporting establishments by major industry groups for 1939–1944. From this it will be seen that the industrial use of electricity has more than doubled in the last five years.

Purchases of electricity by the firms reporting were placed at 108 billion kilowatt-hours in 1943 and 119 billion kilowatt-hours estimated for 1944. The sum of the non-coincident demands for purchased power was placed at 22.9 million kilowatts for 1943 and 23.5 million kilowatts for 1944. Generation by the reporting establishments was estimated at 51 billion kilowatt-hours for 1943 and 53 billion kilowatt-hours for 1944. The capacity of generators, exclusive of motor-generator sets, was indicated to be 11.8



million kilowatts at the end of 1943. Table 2 gives these figures for the years 1939–1944. From this it will be apparent that most of the increased use of electricity for industrial purposes has been supplied by the electric utilities. Purchased energy for 1944 was estimated as nearly three times that of 1939, whereas privately generated energy was expected to increase only about 66 per cent.

It will be observed further from this tabulation that the generating capacity owned by reporting establishments increased 21 per cent from 1939 to 1943.

TABLE 2—ELECTRICITY REQUIREMENTS OF REPORTING ESTABLISHMENTS 1939–1944

Billions of Kilowatt-Hours and Millions of Kilowatts

Year	Purchases, Kwhr	Generation, Kwhr	Generating Capacity, Kw
1944	119	53	...
1943	108	51	11.8
1942	83	46	11.2
1941	68	41	10.5
1940	52	36	10.0
1939	43	32	9.7

The increasing intensity of use of industrial generating capacity resulting from increasing war loads is reflected in the following annual plant factors:

1939—37 per cent
1940—41 per cent
1941—45 per cent
1942—46 per cent
1943—49 per cent

The relationships between kilowatt demand and kilowatt-hours, for both purchased and generated energy in terms of load factors, are as follows:

	Annual Load Factors, Purchases, Per Cent	Annual Load Factors, Generated, Per Cent
1939	40	52
1940	43	55
1941	48	58
1942	49	60
1943	54	62
1944	58	64

From the above it will be seen that the annual load factor for purchased energy is expected to rise from 40 per cent in 1939 to 58 per cent in 1944, a rise of 18 points, whereas the average load factor for generation is expected to increase 12 points during this period. While these figures represent an average, the annual load factors increased in all the major industry groups, except two. For example, in the automobile and transportation groups the load factors of electricity purchased increased from 28 to 51 per cent, and from 26 to 55 per cent, respectively; and those for energy generated increased from 40 to 57 per cent and from 22 to 34 per cent, respectively. Load factors in the chemical and non-ferrous metal groups, which were relatively high in 1939 (55 and 58 per cent, respectively) also had notable increases to 77 and 80 per cent.

The accompanying chart shows the industrial use of electricity among the classified groups, proportionately arranged for geographic divisions of the country.

In the area east of the Mississippi River the estimated requirements for 1944 are 123 billion kilowatt-hours, or three-fourths of those for all the reporting establishments in the United States. The East North Central division shows the greatest use, followed closely by the Middle Atlantic division. The largest growth in electricity consumption for the period covered was in New York State, with 10 billion kilowatt-hours. California, Ohio and Pennsylvania each increased approximately 7 billion kilowatt-hours. The largest increases in per cent were in Nevada where industrial use of power in 1944 is expected to be almost fourteen times that used in 1939, and in Arkansas where the use in 1944 is expected to be eight times that in 1939. These increases are, of course, largely attributed to war loads.

TABLE 1—ELECTRICITY REQUIREMENTS OF REPORTING ESTABLISHMENTS BY MAJOR INDUSTRY GROUPS 1939–1944

(In Order of 1944 Estimated Consumption)

Industry Group	Thousands of Kilowatt-Hours 1939	1940	1941	1942	1943	1944
Manufacturing industries:						
Chemicals	9,356,998	12,029,304	15,603,840	20,572,432	28,929,840	31,859,753
Non-ferrous metals	6,085,358	7,921,793	10,551,754	15,255,157	23,973,689	28,901,486
Iron and steel	12,781,648	15,410,043	19,445,380	20,981,457	24,275,320	25,192,502
Paper	9,462,556	10,480,157	11,728,043	11,786,616	11,924,661	11,980,422
Textile	6,272,654	6,794,130	8,417,166	9,016,242	9,256,725	9,278,018
Transportation equipment	493,310	797,086	1,635,927	4,246,279	7,099,456	8,071,418
Stone, clay and glass	4,503,209	4,969,940	6,119,863	6,436,579	6,073,439	5,978,431
Food	4,521,733	4,591,818	5,128,200	5,508,056	5,891,692	5,970,138
Petroleum and coal	3,111,936	3,442,194	3,859,441	4,039,664	4,813,565	5,753,495
Machinery, except electrical	1,805,704	2,322,262	3,295,827	4,448,622	5,455,951	5,672,008
Automobiles	2,432,205	2,991,733	3,610,045	3,404,618	4,458,042	4,590,838
Electrical machinery	1,392,951	1,761,289	2,441,703	2,918,404	3,526,086	3,747,589
Rubber	1,557,227	1,631,208	2,029,387	1,742,699	1,978,409	2,034,946
Lumber	1,132,235	1,264,068	1,406,424	1,478,662	1,521,217	1,525,728
Miscellaneous	339,803	382,167	504,289	629,232	781,873	810,939
Furniture	412,043	466,561	551,277	569,675	600,657	604,609
Leather	294,516	297,335	356,663	377,345	377,585	373,409
Printing	289,933	308,946	335,759	338,618	344,056	346,165
Tobacco	81,255	88,435	97,307	105,196	107,527	108,432
Apparel	72,585	78,060	92,996	99,878	101,779	102,673
All manufacturing	66,399,859	78,028,529	97,211,291	113,955,431	141,491,569	152,902,999
Extracting industries:						
Coal mining	3,035,015	3,420,799	3,655,573	4,176,481	4,552,160	4,617,680
Metal mining	1,993,912	2,296,788	2,606,675	2,945,320	3,168,922	3,234,810
Non-metallic mining	536,477	593,317	746,321	797,457	809,118	805,994
Petroleum and natural gas	549,001	605,903	602,405	594,743	619,442	619,050
All extracting	6,114,405	6,916,807	7,610,974	8,514,001	9,149,642	9,277,534
Government	609,688	835,131	1,476,199	3,182,736	5,306,903	5,983,123
All industries	73,123,952	85,780,467	106,298,464	125,652,168	155,948,114	168,163,656

Alex Bailey Becomes Vice-President of Commonwealth Edison Co.

The Board of Directors of Commonwealth Edison Co., Chicago, have elected Alex D. Bailey Vice-President in Charge of Engineering and Operation, succeeding H. B. Gear who will retire from active service on June 30.

Mr. Bailey entered the Company's employ as a draftsman in 1903 and subsequently became chief engineer of the Fisk and Quarry generating stations, superintendent of generating stations and assistant chief operating engineer. He was made chief operating engineer in 1936 and assistant to Vice-President Gear in 1943. He was Vice-President of the American Society of Mechanical Engineers in 1936–37 and is Vice-Chairman of the Board of Trustees of Illinois Institute of Technology.

R. O. Muller Dead

Richard O. Muller, who recently retired as chief engineer of The Terry Steam Turbine Co., after 18 years in that capacity, died on June 4.

Mr. Muller had been identified with the steam turbine field practically all his adult life. Starting at an early age with Parsons in England, he later came to this country and was employed by E. W. Bliss Co. of Brooklyn as a turbine engineer. He joined The Terry Steam Turbine Co. in 1915 and became chief engineer in 1926.

Electric Energy Demands Up

The Federal Power Commission announced on May 31 that April peak demands of the principal electric utility systems of the country aggregated 35,851,358 kw, an increase of 10.3 per cent above last year's April demand. Corresponding electric energy requirements amounted to 18,266,179,000 kw-hr, a gain of 8.3 per cent over April 1943. Comparable percentage increases reported for the preceding month were 10.3 per cent for demand and 11.0 per cent for energy in comparison with March 1943.

The Commission stated that estimates of December 1944 peak demands made by the Class I electric utility systems in their April reports amounted to 38,585,643 kw. Utility estimates of energy requirements for the year 1944 summarized from the same reports totaled 227,855,165,000 kw-hr. These estimates for 1944 indicate expected increases over 1943 of about 1,525,000 kw in December demands and some 12,735,000,000 kw-hr in annual energy needs. Such increases would represent gains of 4.1 per cent in demand and 5.9 per cent for energy.

The nameplate rating of new generating capacity placed in service during April totaled 254,080 kw. Scheduled net additions to the installed generating capacity of the principal systems are given as 871,500 kw by the end of 1944, and an additional 589,000 kw by December 31, 1945. These figures include only those additions actually on order and authorized by the War Production Board for installation in the year indicated.

A.B.M.A. Meet at Skytop

The largest attendance in many years characterized the 56th Annual Meeting of the American Boiler Manufacturers and Affiliated Industries, which was held at Skytop Lodge, Skytop, Pa., from June 4 to 7. The various sessions scheduled on the program were fully attended and the social activities, which are an attractive feature of these gatherings, helped considerably to the success of the meeting.

Officers elected for the coming year were: President—Albert C. Weigel, Combustion Engineering Company; Vice-President—Frank G. Brinig, Erie City Iron Works; and Secy. and Treas.—A. C. Baker.

More than the usual number of people participated in the golf tournaments and other programs, and the Annual Dinner was attended by 167.

NEW CATALOGS AND BULLETINS

Any of these publications will be sent on request

Conductivity Measurement

Leeds and Northrup Company has just revised its catalog, "Apparatus for Electrolytic Conductivity Measurements in Laboratory and Plant." This 44-page publication (EN-95 1944) presents much the same data about methods of measurement and notes for selection and use of the apparatus as did the previous edition, but in addition, it illustrates and describes a Signalling Conductivity Controller and several new industrial cells which have become available since the earlier edition was issued.

Coal Mine Directory

The Chesapeake and Ohio Railway has issued an attractive 55-page "Coal Mine Directory 1944" presenting useful information as to bituminous coal originating at mines in the region served by this railway. The Directory contains the following listings: 1—Operating Companies, showing mine name and number; 2—Mines, arranged alphabetically, showing item numbers and code numbers of railway stations; 3—Stations at which mines are located; 4—Geographical Arrangement of Mines, together with 5 full-page maps in color; and 5—Sales Agents. The book is spiral bound and a large folded map of the districts and fields served by the C and O Railway is included.

Insulated Pipe Units

The Ric-wiL Company has issued a 6-page folder describing the latest improvements incorporated in its insulated pipe units. These comprise a new drive coupler for mechanical or welded conduit connection, a new pre-seal and a welded spiral lock seam running the full length of the conduit. The features of this prefabricated insulated-pipe conduit system are admirably illustrated.

Tube Cleaners

An interesting and colorful 24-page bulletin on Tube Cleaners has been issued by the Elliott Company. This admirably illustrated bulletin (Y-18) covers the entire field of modern practice in this equipment. Latest types of cutter heads and motors to which they are adapted are described. Large cutaway illustrations in color picture the interior construction of various motors driven by air, steam or water. Specialized tube cleaners and special applications for standard equipment are described.

Central Heating

A 6-page folder describing the many advantages of Central Heating for municipalities, large and small housing projects, hospitals and colleges and industrial groups, has been issued by The Ric-wiL Company.

General and Classified Index

COMBUSTION, Volume Fifteen, July 1943 through June 1944

EDITORIALS—

ARTICLES—

AUTHORS—

REVIEW OF NEW BOOKS—

CLASSIFIED INDEX—

Stokers

Miscellaneous

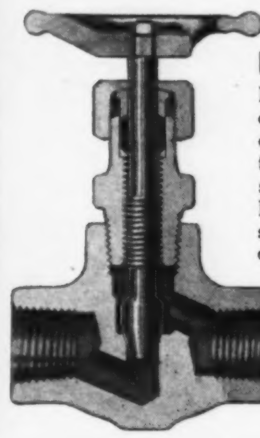
ADVERTISERS IN THIS ISSUE

Edward

GAGE VALVES

FOR services where bar stock valves are often used—gage, meter, dead end and instrument lines, pump vents and Diesel and gas engines—Edward Fig. 152 gage valves have the advantage of much greater strength.

Because they are drop forged steel, the bodies of Edward gage valves have sounder structure and greater strength than bodies machined from a bar. For non-shock service up to 4000 lb at 150 F and in steam service up to 600 lb at 750 F. Made to customary Edward precision and quality standards, yet remarkably low in price because of production runs.



DESIGN DETAILS

Rugged, functional design qualifies Edward Fig. 152 gage valves for long life in tough service. Notice exclusive safety taper threaded bonnet joint, EValloy stainless steel stem with semi-needle disk, knobbed handwheel for easy grip and leverage, back seating shoulder to prevent backing stem out of bonnet and to permit repacking under pressure. Bonnets and packing nuts are EValized to cut corrosion and wear.

DIMENSIONS AND RATINGS

4000 lb at 150 F

600 lb at 750 F — 475 lb at 1000 F

DIMENSIONAL DETAILS

SIZE	1/8"	1/4"	3/8"	1/2"
End to end—Globe	1 13/16	1 13/16	2 1/4	2 3/4
Center to end—Angle	29/32	29/32	1 1/8	1 3/8
Center to top—Open	3 5/8	3 5/8	3 7/8	4
Port diameter	1/8	3/16	1/4	3/8
Weight—lb	1	1	1 1/4	1 1/2

For illustrations, dimensions and descriptions of the Edward line of cast and forged steel valves write for a free copy of the new Edward BETTER VALVES Catalog No. 102.

THE EDWARD VALVE & MFG. CO., INC., • EAST CHICAGO, INDIANA

EDWARD *Steel* VALVES

MEET THE MEN  WHO WANT

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University of Alabama
UNIVERSITY

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CALIFORNIA

MR. GERALD E. CHESS
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The University of Tennessee
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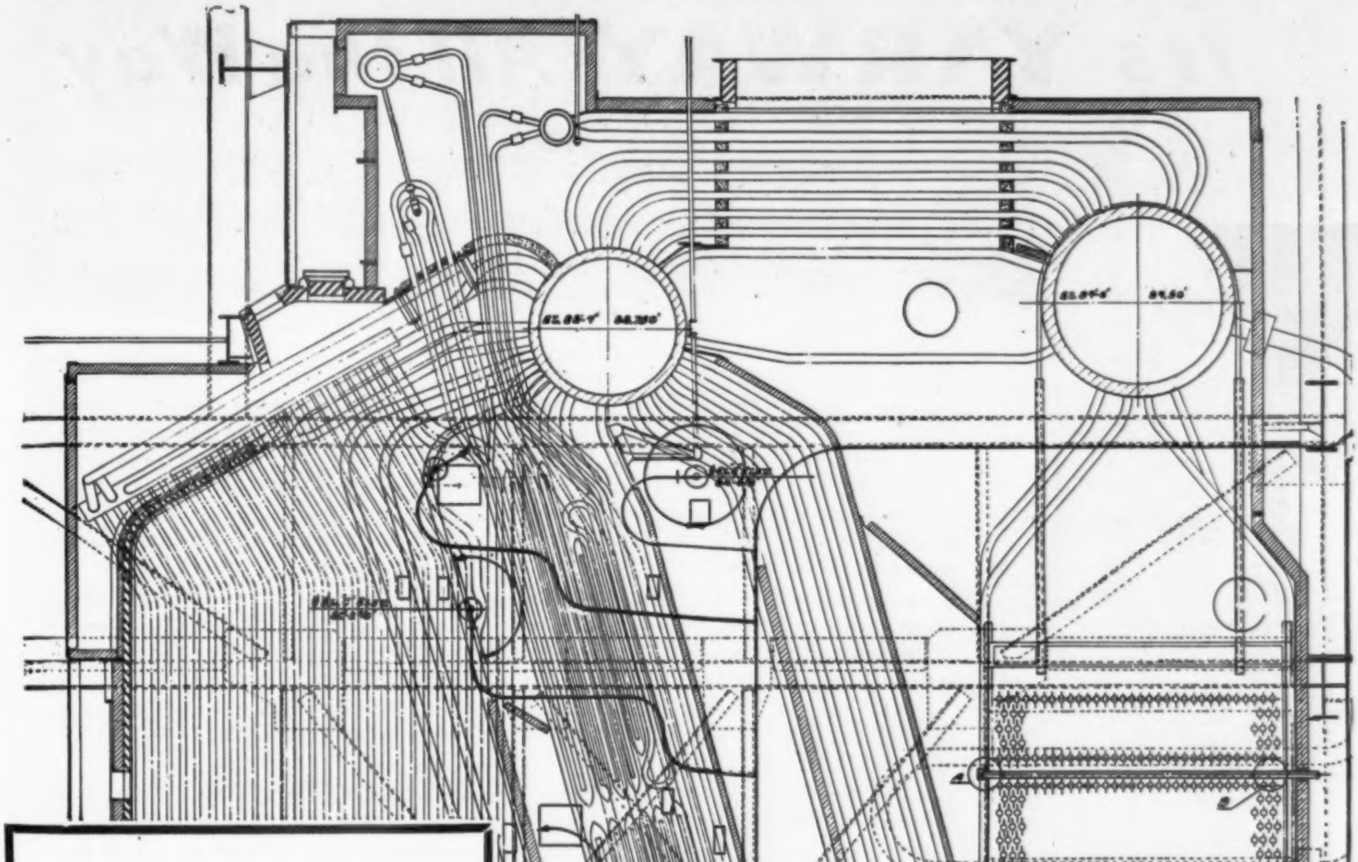
VULCAN ENGINEERED SOOT BLOWER INSTALLATIONS



Two 600,000 lb. per hour Combustion Engineering Co. Boilers installed in a large Eastern Central Station. Boilers generate steam at 1250 lb. per sq. in. at 910° F. Soot Blowers operate from 265 psi. Elements in the first pass are HyVULoy with HyVULoy protective bearings, air cooling and pre-cooling, resulting in long life in the exposed positions. This advantageous location together with slow-speed LG-2 heads keep the superheater clean. Also the use of the overarm support and special sliding seal for large relative movements eliminate element warpage and give easy operation.

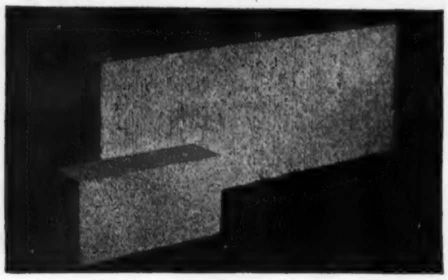
The NEW VULCAN CATALOG fully describing the MODERN VULCAN SOOT BLOWING SYSTEM is now available. Write for your copy.

VULCAN SOOT BLOWER CORPORATION, DU BOIS, PENNA.

Solutions TO YOUR TOUGH INSULATING PROBLEMS!

WHATEVER your insulating problem, there's a Johns-Manville insulation that can solve it efficiently and at minimum cost. For, over the past 86 years, J-M's extensive laboratories have pioneered in the field of industrial insulation. Today J-M offers a wide line of insulating materials, each designed for some specific insulation need, for temperatures up to 2600°. For example:

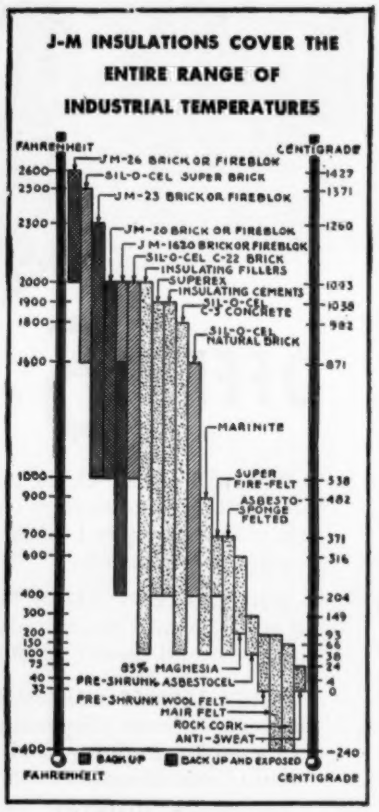
For temperatures to 600° F. J-M 85% Magnesia has been for many years the most widely used block and pipe insulation for temperatures to 600° F. and, in combination with Superex, for higher temperatures. Maintains high insulating efficiency. Standard block sizes 3" x 18", 6" x 36" and 12" x 36"; from 1" to 4" thick.



Furnace insulation up to 2600° F. J-M Insulating Brick and Insulating Fire Brick are available in 7 types, temperature limits from 1600° F. to 2600° F. All provide light weight, low conductivity. New Insulating Fireblok, now ready in all four Fire Brick types, are 5 times larger for speedier, more economical installation.

For steam lines up to 700° F. Use J-M Asbesto-Sponge Felted Pipe Insulation for efficiency, high salvage and resistance to abuse. For temperatures over 700° F. use with Superex. In 3-ft. lengths 1" to 3" thick.

Insulation for temperatures to 1900° F. J-M Superex Blocks have long been standard for this service. High heat resistance, low thermal conductivity. Sizes 3" x 18", 6" x 36" and 12" x 36"; from 1" to 4" thick.



For more details on these materials, and on the complete J-M Insulation line, write for Catalog GI-6A. Address: Johns-Manville, 22 East 40th Street, New York 16, New York.

JOHNS-MANVILLE JM PRODUCTS

Johns-Manville INDUSTRIAL INSULATIONS

FOR EVERY TEMPERATURE ... FOR EVERY SERVICE

ADD *ALL 3* TO YOUR MODERNIZATION PLANS

THROUGH

PREHEAT *Engineering*

If you are planning to modernize a boiler plant, oil refinery heater or other industrial furnace, don't overlook the possibilities for more effective use of preheated air.

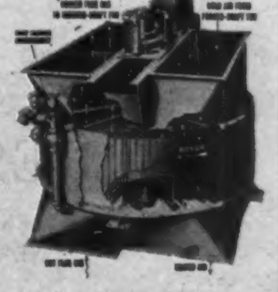
IMPROVED COMBUSTION. A shorter, hotter flame helps complete combustion before gases leave the furnace. Higher rates of liberation increase furnace capacity. High-moisture powdered coal and low grade fuel such as screenings, coke breeze, etc., may be effectively burned.

BETTER HEAT RECOVERY. Flue gas temperatures may be reduced 200 to 500 degrees, and the heat returned with minimum loss to the incoming combustion air. Thermal efficiency of the furnace may be increased up to 10% or more.

SAVINGS IN PLANT MATERIALS. The Ljungstrom Preheater is unusually compact, effecting savings in weight of both heating surface and supporting structure. In many cases, the Ljungstrom weighs less than half as much as other heat recovery installations with the same capacity.

ENGINEERING SERVICE. The engineering staff of the Air Preheater Corporation is prepared to assist you in applying either the standard or special types of Ljungstrom Preheaters to your present plant, or to assist you in engineering it as an integral part of new units.

THE LJUNGSTROM AIR PREHEATER. Either vertical or horizontal types consist of a cellular rotor which "soaks up" heat from flue gas as it passes through, and transfers it to the cold, incoming air. It works on the continuous regenerative flow principle, thus giving maximum heat transfer with minimum weight and size.



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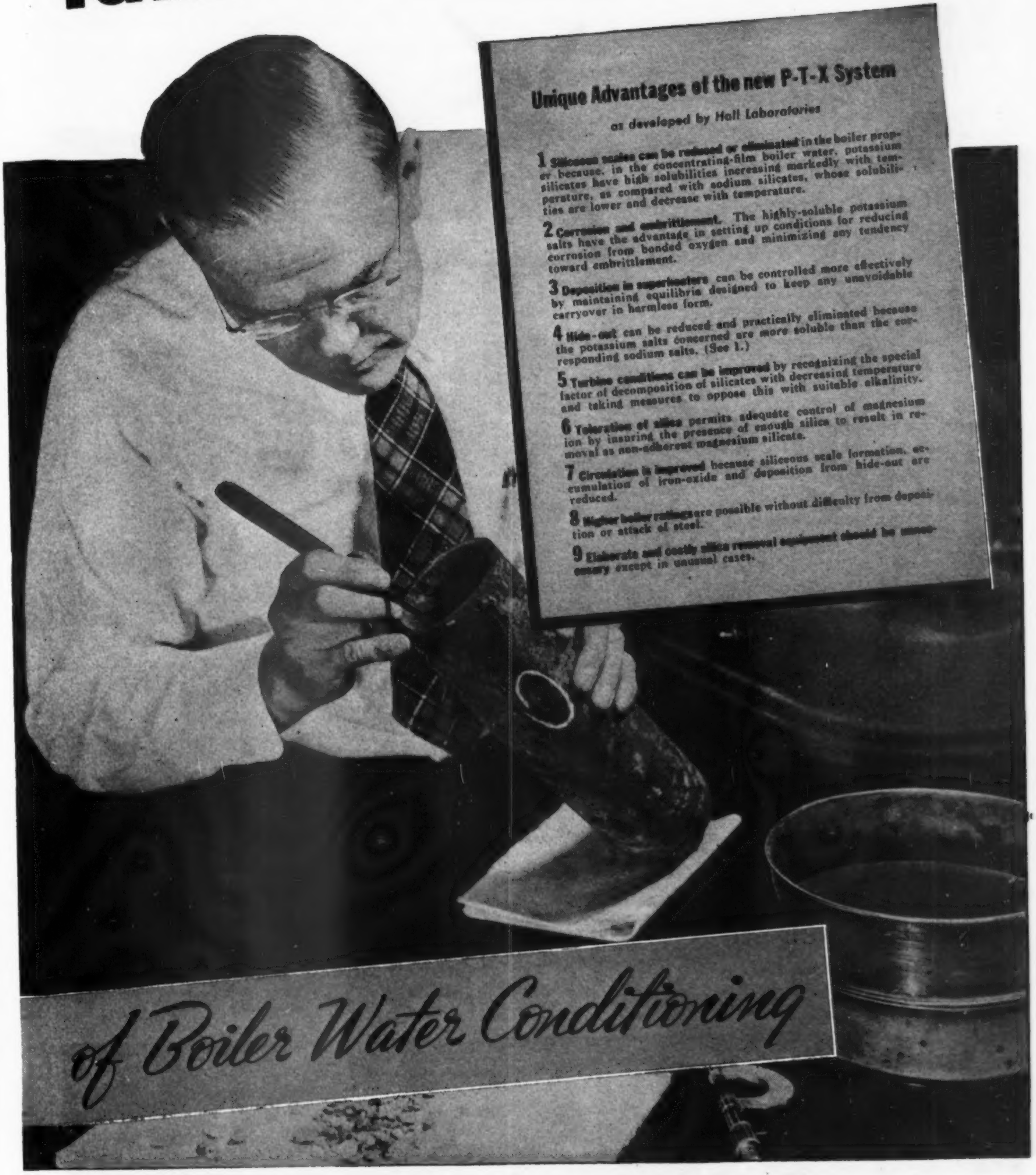
AIR PREHEATER

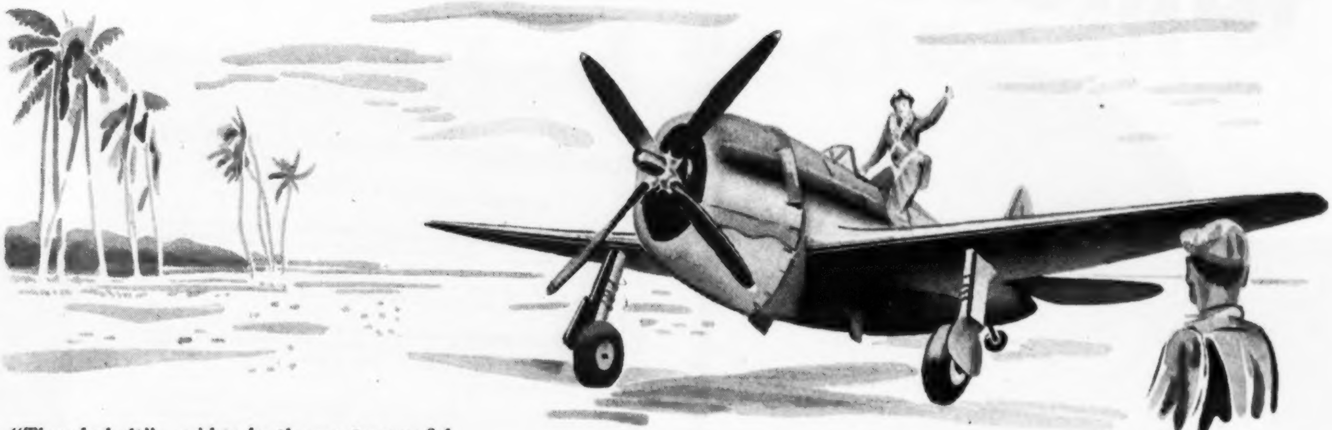
CORPORATION

Executive Offices: 60 East 42nd Street • New York 17, N. Y. • Plant: Wellesville, N. Y.

famous boiler service



The Army's Answer to a "MUST!"



"Thunderbolt"—said to be the most powerful single seat fighter in the world, with four .50 caliber fixed machine guns mounted in each wing panel, a flying speed of more than 400 m. p. h.—and a diving speed greater than the speed of sound.

"Musts" are constant in industrial, as in military achievements. And the only "stock-bin" out of which "musts" are solved is the stock-bin of experience and specialized application. POWELL, for nearly one hundred years, has made valves, and valves only . . . valves for all flow control requirements . . . valves for the "must" requirements in all fields of industry . . . in war or peace . . . through ten decades of industrial progress. Our experience in producing *the* valve to do *the* specific job—"to meet the must"—is yours on request.

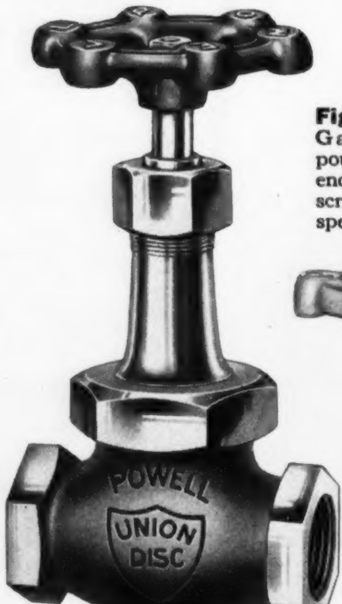


Fig. 150 (above)—Bronze "Union Disc" Globe Valve for 150 pounds W. P. Has screwed ends, union bonnet, and renewable vulcanized composition disc—especially suitable for throttling service—for controlling low-pressure steam, oil, water, gas, etc.

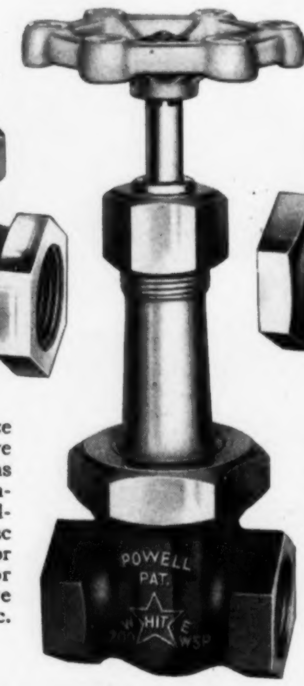


Fig. 375 (below)—Bronze Gate Valve for 200 pounds W.P. Has screwed ends, union bonnet, inside screw rising stem and a special hard bronze disc.

Fig.1708(above)—Bronze Globe Valve for 200 pounds W.P. Has screwed ends, union bonnet, renewable seat and regrindable, renewable hard bronze semi-cone plug type disc—especially suitable for throttling service—for controlling low-pressure steam, oil, water, gas, etc.

The Wm. Powell Co.

Dependable Valves Since 1846

Cincinnati 22, Ohio

POWELL VALVES

DOWELL INDUSTRIAL CHEMICAL CLEANING SERVICE

Increasing Industry's Productive Power

A quick—safe—efficient method of chemically removing water- or steam-deposited scales and sludge from all types of heat exchange equipment is provided by Dowell to help restore and increase industry's productive efficiency.

This proven chemical service is completely mobile and readily available at many strategic points.

The close cooperation between Dowell and its parent organization, The Dow Chemical Company, is fully utilized to provide industry with advanced methods and improved techniques in chemical cleaning.

Consult the nearest Dowell office for full information.

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Kansas City • Long Beach • Salem, Ill. • Mt. Pleasant, Mich.
Houston • Wichita, Kan. • Casper, Wyo.

Progress and Power in the TEXTIL

Perhaps no other industry is quite as dependent on low cost, dependable electrical energy as textile and rayon manufacturers. America's great Public Utilities have met all the requirements of this ever expanding group in widely scattered sections all over the United States.

American Blower engineers, too, have contributed much to the task of making rayons and cloth of all types at low cost. For many years American Blower fans, blowers, air conditioning units and humidifiers have been maintaining healthful, efficient working conditions in the plants of the textile and rayon industries.

Furnishing vital equipment of standard as well as specialized types for handling of air in industry, and building mechanical draft equipment, dust collectors and fluid drives, is our job. May we co-operate with you?

MECH. DRAFT · AIR-CONDITIONING · AMERICAN BLOWER · FLUID DRIVES · DUST COLLECTORS

AMERICAN BLOWER

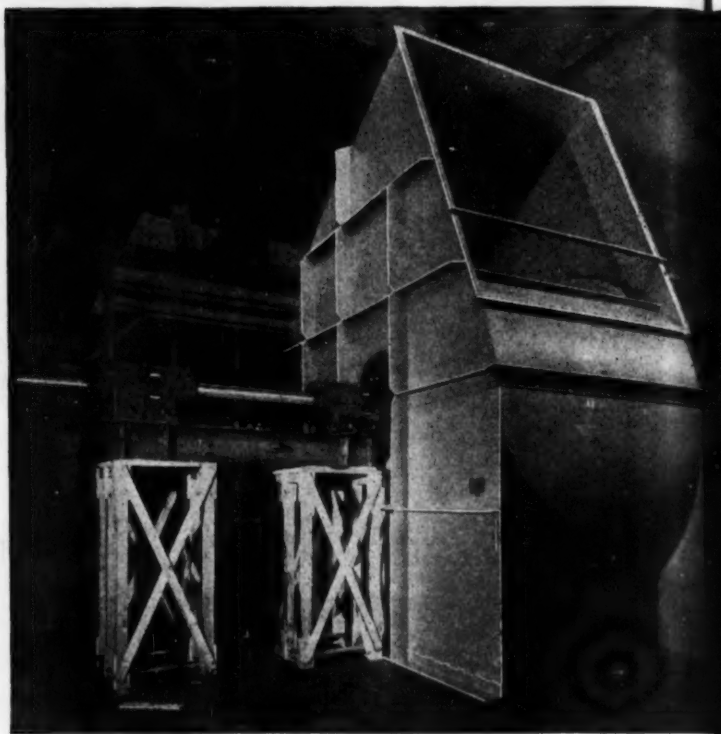
ARMY E NAVY

For Production "Well Done"

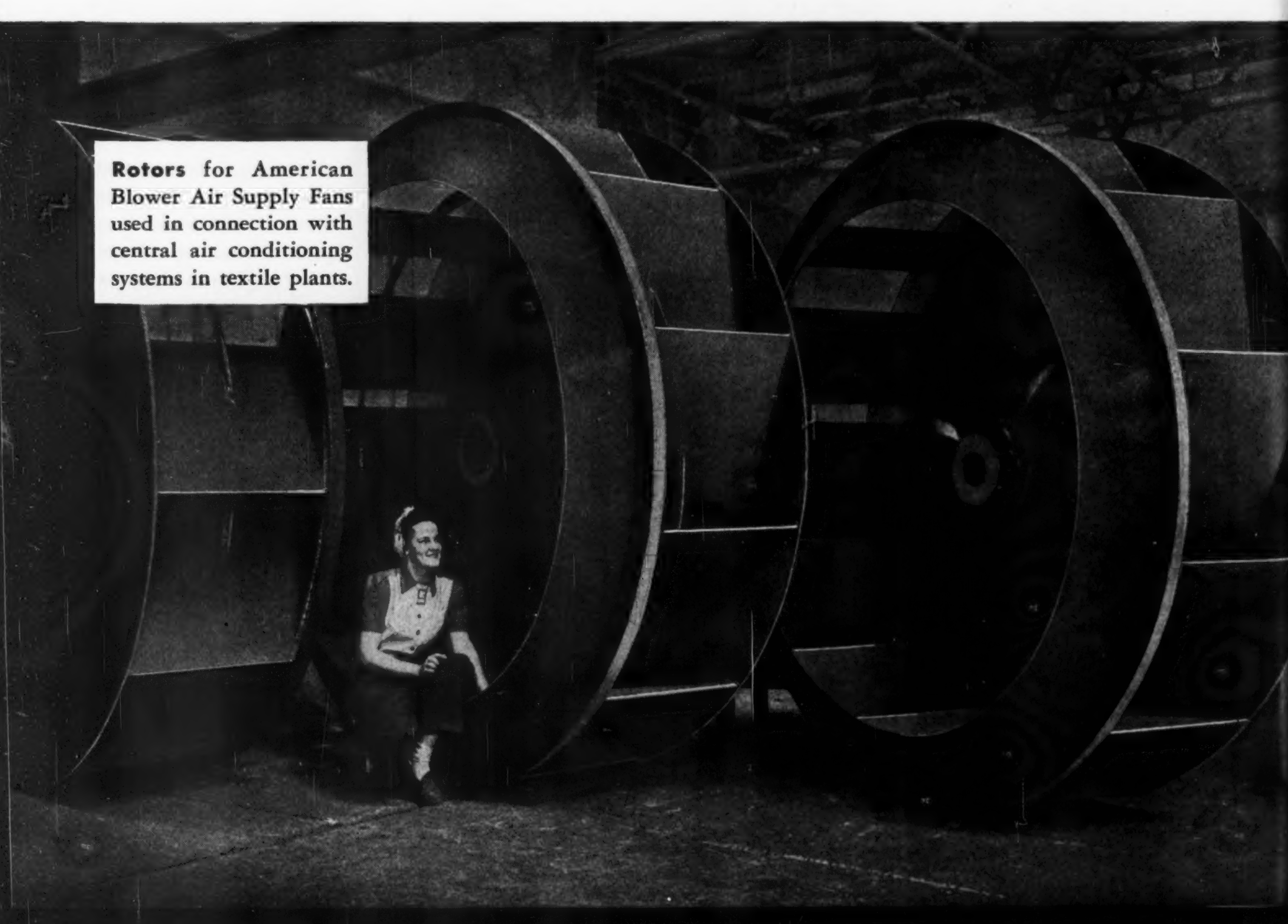
AMERICAN BLOWER CORPORATION, DETROIT, MICH.

CANADIAN SIROCCO COMPANY, LTD., WINDSOR, ONT.

Division of American Radiator & Standard Sanitary corporation

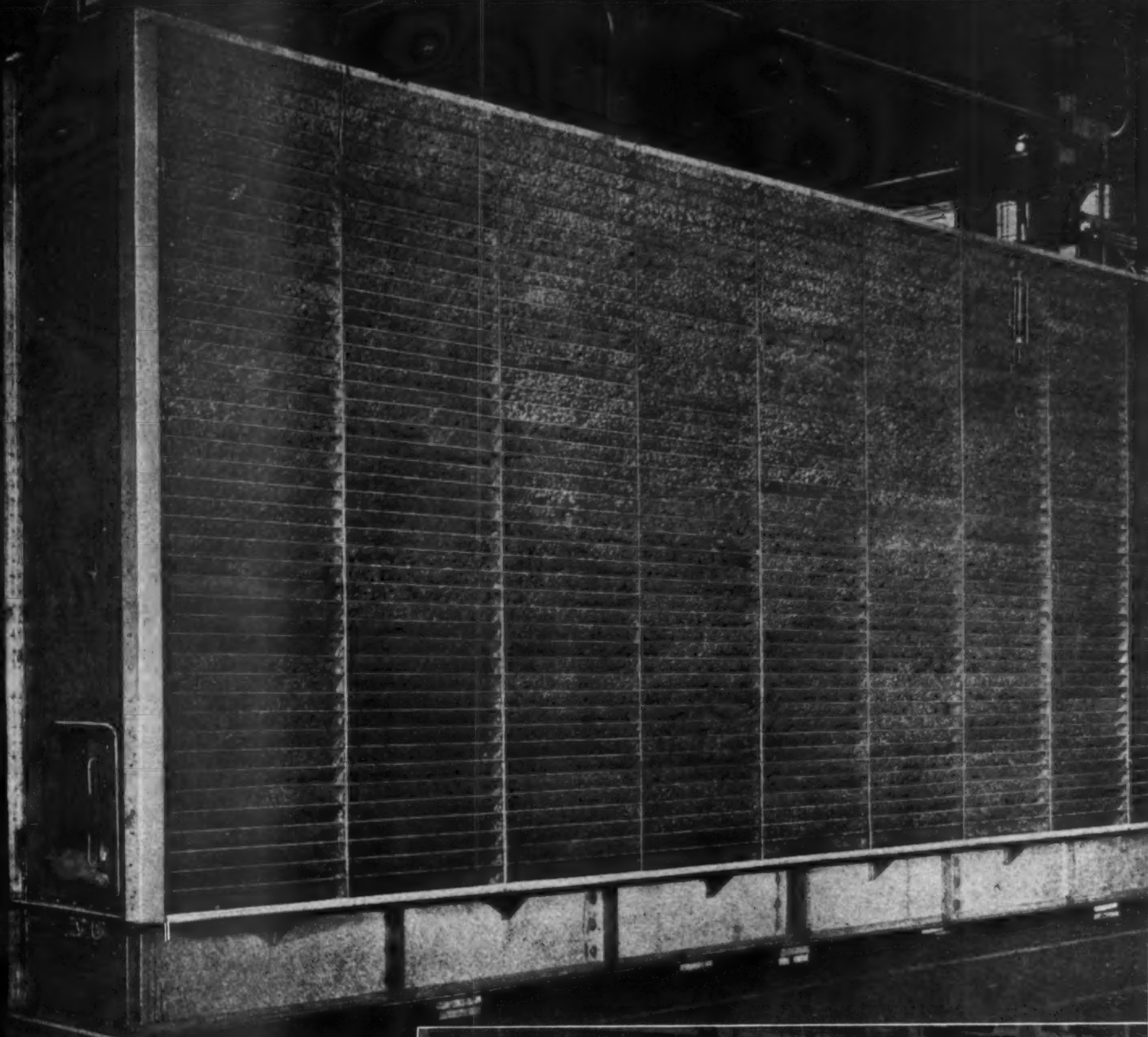


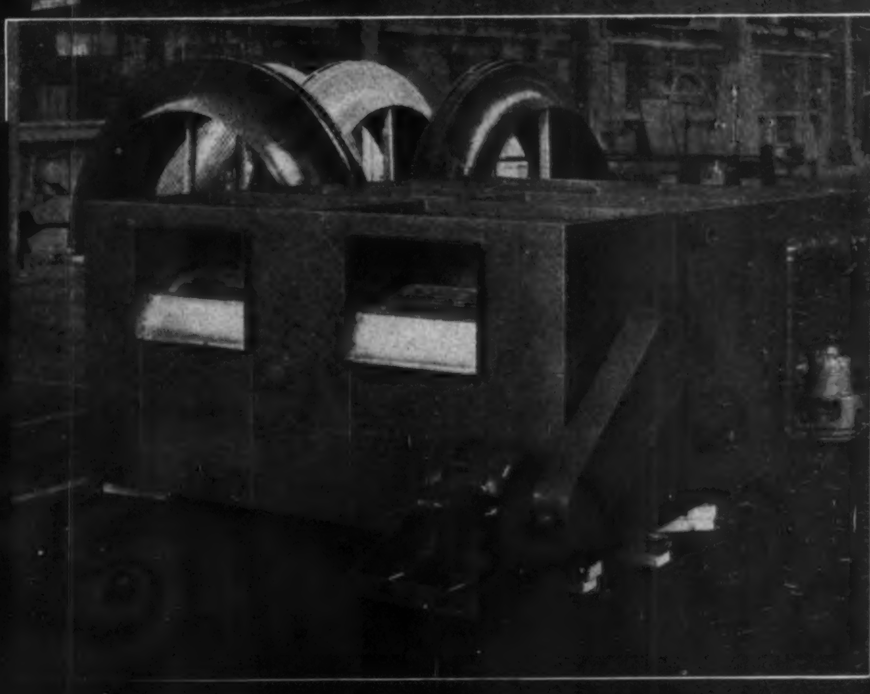
American Blower Fan for exhausting organic fumes from spring room machines in a rayon plant.



Rotors for American Blower Air Supply Fans used in connection with central air conditioning systems in textile plants.

LAND RAYON INDUSTRIES

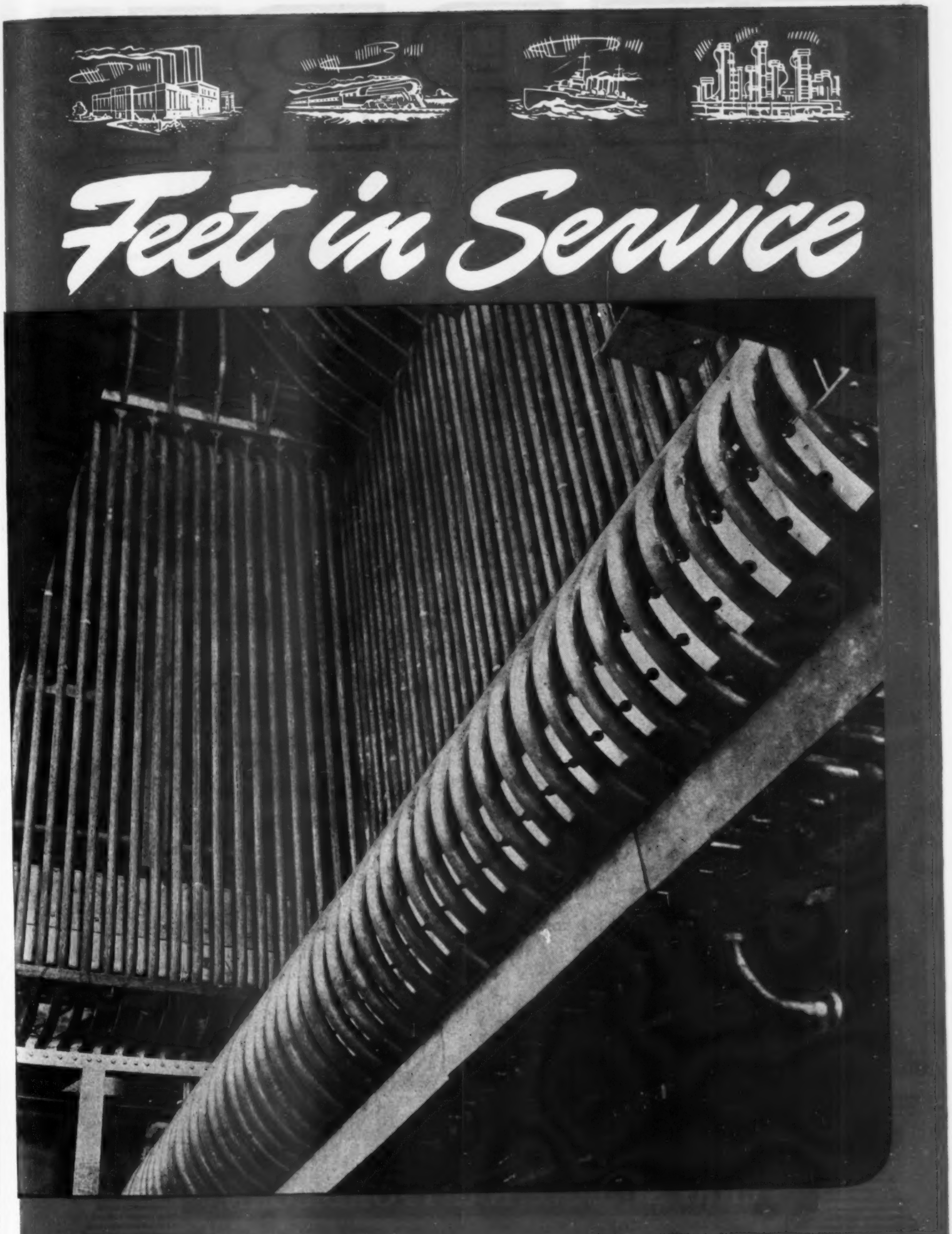




(Above) American Blower Central System Air Conditioner and Washer for a rayon plant.

• • •

(At Right) Air Conditioning and Humidifying unit built by American Blower for one of America's largest textile mills.


Feet in Service

He won't dodge this-

Don't *you* dodge this!

The kid'll be right there when his C. O. finally gives the signal . . .

There'll be no time to think of better things to do with his life. THE KID'S IN IT FOR KEEPS—giving all he's got, *now!*

We've got to do the same. This is the time for us to throw in everything *we've* got.

This is the time to dig out that *extra* hundred bucks and spend it for Invasion Bonds.

Or make it \$200. Or \$1000. Or \$1,000,000 if you can. There's no ceiling on this one!

The 5th War Loan is the biggest, the most vitally important financial effort of this whole War!

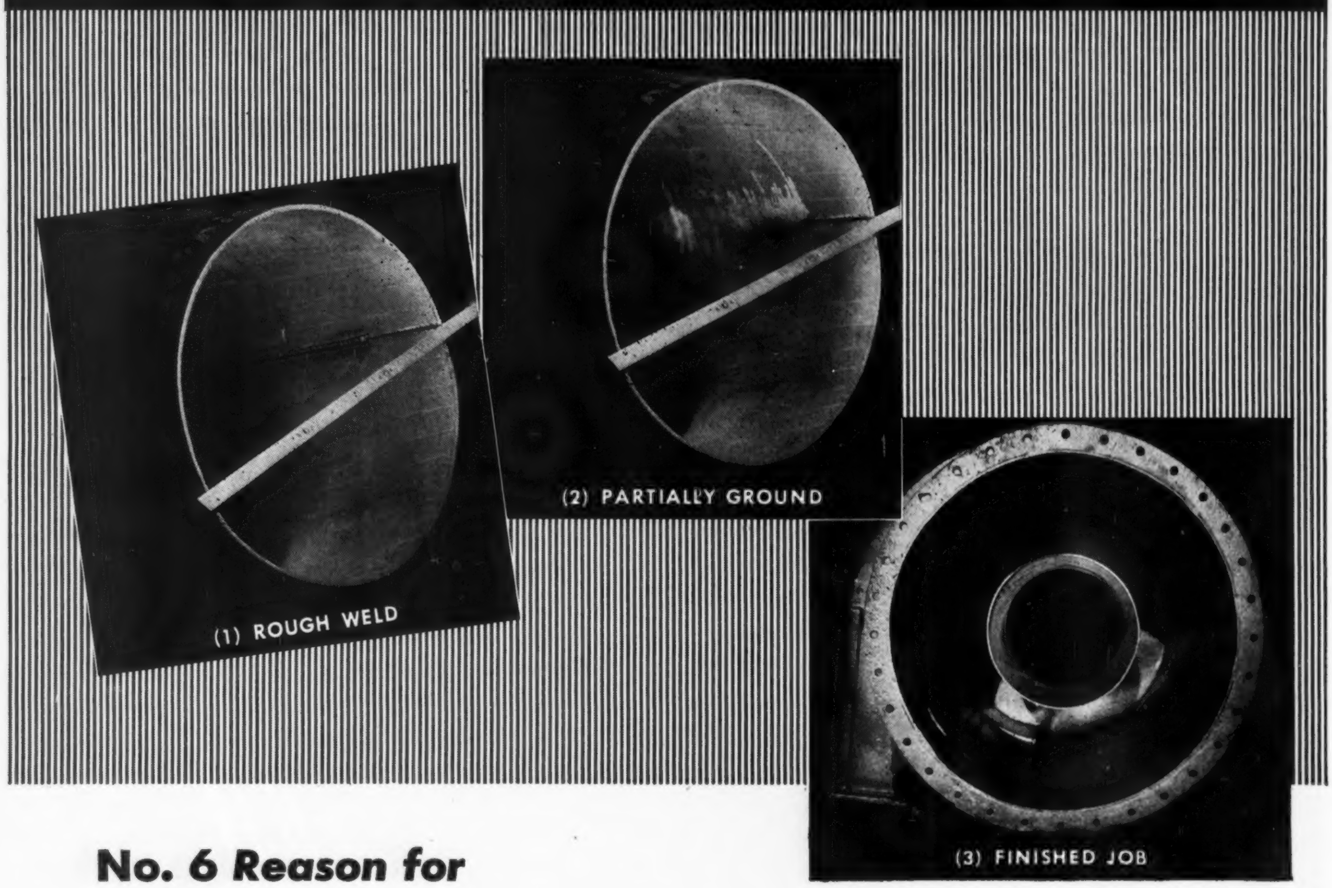
5TH WAR LOAN

Back the Attack! - BUY MORE THAN BEFORE

COMBUSTION PUBLISHING COMPANY, INC.

This is an official U. S. Treasury advertisement—prepared under the auspices of Treasury Department and War Advertising Council

Next to Split-Duct Manifolds . . . INNER WELDS GROUND SMOOTH



No. 6 *Reason for*

Buell's High Efficiency, Low Maintenance, Long Life

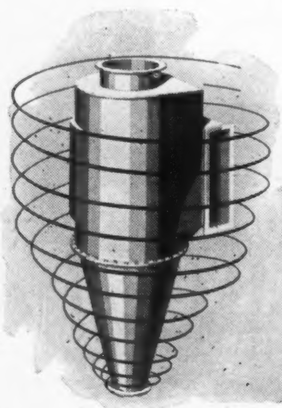
• THE PROPER FINISHING of the inner surface of all welds in Buell (van Tongeren) Cyclones has a direct bearing upon first, their operating efficiency, second, their length of life.

Any projection in a gas stream will affect the efficiency of a dust collector. Surface irregularities create undue turbulence and cause the reentrainment in the gas stream of previously separated dust particles. Moreover, if the weld-bead is not ground smooth, rapid erosion of the surface beyond the bead will take place, due to the formation of a local eddy current at this point. And continued erosion will shorten the life of the stoutest dust collector.

Smoothly ground inner welds are one more reason for Buell's high efficiency, long life, trouble-free operation, and low maintenance cost. Reasons supported by the wide use of Buell Dust Recovery Systems throughout industry.

Write for a copy of the illustrated book—"The van Tongeren System of Industrial Dust Recovery," containing facts about this patented system, interesting alike to engineer and executive.

BUELL ENGINEERING COMPANY, INC.
Suite 5000, 70 Pine St., New York 5, N. Y.
Sales Representatives in Principal Cities



buell
DUST RECOVERY SYSTEMS

BUELL FEATURES	RESULT IN	PRODUCE
SHAVE-OFF LARGE DIAMETERS EXTRA-THICK METAL LARGE OUTLETS INNER WELDS GROUND SMOOTH CORRECTLY DESIGNED HOPPERS SPLIT-DUCT MANIFOLDS	HIGH COLLECTION EFFICIENCY LESS FAN BLADE WEAR LOW DRAFT LOSS LOW POWER CONSUMPTION HIGH TEMPERATURE RESISTANCE UNLIMITED CAPACITY NO MOVING PARTS FREE DUST FLOW	GREATER RECOVERY LOW MAINTENANCE LOW OPERATING COST LONG LIFE NO CLOGGING

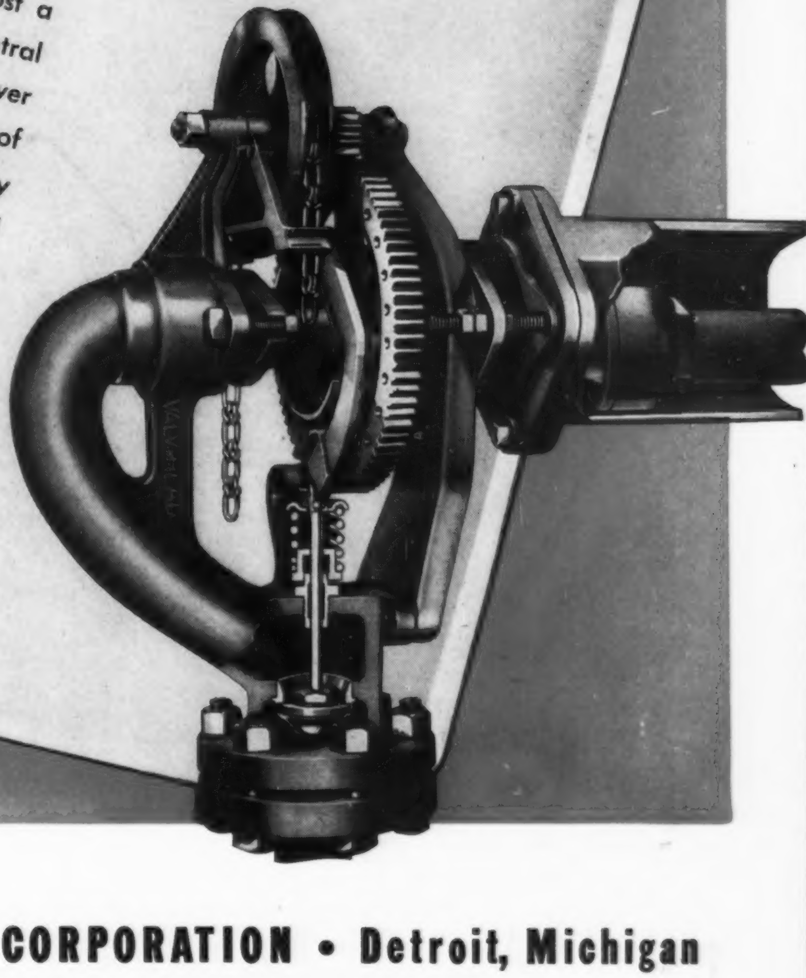
DESIGNED TO DO A JOB, NOT JUST TO MEET A "SPEC"

Where Soot Blowers Have to be Good

The Choice is Almost Invariably DIAMOND

Diamond Soot Blowers are almost a foregone conclusion in huge central station and industrial steam power plants. An overwhelming majority of engineers choose them because they know Diamond Blowers will stand the extreme severity of service—keep boilers cleaned of soot and slag and require little attention from the service man.

More than 80% of all the soot blowers on modern power boilers are Diamond.



DIAMOND POWER SPECIALTY CORPORATION • Detroit, Michigan

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